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Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The number of fish that encounter fishing gear is greater than the number of fish retained as catch. The proportion of this difference that die from the encounter is defined as fishing-related incidental mortality (FRIM). FRIM estimates are required for improved stock assessments, but they are difficult to attain and vary across fisheries. To cope with this challenge we review and evaluate the scientific knowledge on FRIM. First, we review the different mortality components of FRIM (i.e., avoidance, escape, depredation, drop-out, on-board, short-term release, and delayed mortality) in relation to how a fish responds to different aspects of a fishery encounter (e.g., handling). To better understand how fish respond to a fishing encounter, different fishing factors (e.g., gear type) that act in consort with extrinsic (e.g., water temperature) and intrinsic (e.g., fish size) factors elicit different fish responses that can lead to the different types of mortality (e.g., acute) were examined. A fish response to a stressor (i.e., factor) is a combination of the magnitude and duration of the stressor itself. The initial fish response includes acute physiological stress and injury, followed by behaviour changes, chronic stress, and increased risk of infection. Next, a review was done to provide an up-to-date accounting of the mortality rate information available on estimates of FRIM for Pacific salmon (*Oncorhynchus* spp.). We created an interactive and searchable catalogue of evidence from predominantly primary literature using standardized systematic mapping protocols, with a focus on coding information to determine study reliability and relevance. Next, we synthesize the factor and mortality information to provide recommendations on the use of five major mortality risk factors that are linked to FRIM. Each factor (capture, handling, injury, water temperature, and predators) is scaled to a mortality risk to provide guidance on evaluating FRIM estimates. The recommendations from this work are focussed on addressing the current knowledge gaps and examining FRIM in broader physiological and ecological context. Ideas for future work include researching cumulative impacts, sub-lethal effects, drop-off mortality, and predation. We have chosen a fish-centric hybrid approach that focusses first on understanding factors that drive mortality, and then on mortality estimates. As such, this paper is not meant as the definitive guide on FRIM but a transparent, defensible, and rigorous evaluation of the primary evidence base for making future decisions about FRIM. Further guidance on how to use the information herein is part of an accompanying CSAS research document.

Examen et évaluation de la mortalité accidentelle des saumons du Pacifique liée à la pêche

RÉSUMÉ

Le nombre de poissons qui entrent en contact avec des engins de pêche est plus élevé que le nombre de poissons conservés en tant que captures. La proportion de poissons qui meurent lorsqu'ils entrent en contact avec des engins de pêche est définie comme étant la mortalité accidentelle liée à la pêche. Les estimations de la mortalité accidentelle liée à la pêche sont nécessaires pour améliorer les évaluations des stocks, mais elles sont difficiles à réaliser et varient selon les pêches. Afin de composer avec ce défi, nous passons en revue et évaluons les connaissances scientifiques sur la mortalité accidentelle liée à la pêche. Pour commencer, nous passons en revue les différentes composantes de la mortalité accidentelle liée à la pêche (c.-à-d. la mortalité par évitement, évasion, déprédation, décrochage, après rejet, à bord, à court terme et différée) par rapport à la façon dont un poisson répond aux différents aspects d'une rencontre avec des engins de pêche (p. ex., la manipulation). Afin de mieux comprendre comment le poisson répond à une rencontre avec des engins de pêche, on a examiné la façon dont les différents facteurs liés à la pêche (p. ex., le type d'engin) agissant de concert avec les facteurs extrinsèques (p. ex., la température de l'eau) et les facteurs intrinsèques (p. ex., la taille des poissons) déclenchent différentes réactions des poissons qui peuvent entraîner différents types de mortalité (p. ex., mortalité aiguë). La réaction d'un poisson à un agent de stress (c.-à-d. un facteur) est une combinaison de l'ampleur et de la durée de l'agent de stress lui-même. La première réaction des poissons comprend du stress physiologique aigu et des blessures graves, suivis par des changements comportementaux, du stress chronique causé et un risque accru d'infection. Nous avons ensuite effectué un examen afin de présenter un compte rendu à jour des renseignements disponibles sur les estimations de la mortalité accidentelle liée à la pêche pour le saumon du Pacifique (*Oncorhynchus* spp.). Nous avons créé un catalogue interactif et interrogeable de données probantes provenant surtout des publications spécialisées à l'aide de protocoles normalisés de cartographie systématique, en mettant l'accent sur l'information codée pour déterminer la fiabilité et de la pertinence de l'étude. Ensuite, nous avons fait la synthèse des renseignements sur les facteurs et la mortalité pour formuler des recommandations concernant l'utilisation des cinq principaux facteurs de risque qui sont associés à la mortalité accidentelle liée à la pêche. Chaque facteur (capture, manipulation, blessures, température de l'eau, prédateurs) est associé à un risque de mortalité pour fournir une orientation pour l'évaluation des estimations de la mortalité accidentelle liée à la pêche. Les recommandations tirées de ces travaux visent d'abord à combler les lacunes dans les connaissances actuelles et à examiner la mortalité accidentelle liée à la pêche dans un contexte physiologique et écologique élargi. Les idées pour les travaux futurs comprennent des recherches sur les effets cumulatifs, les effets sublétaux, la mortalité après rejet et la prédation. Nous avons choisi une approche hybride centrée sur les poissons qui met l'accent d'abord sur la compréhension des facteurs de mortalité, puis sur les estimations de la mortalité. À ce titre, le présent document ne se veut pas le guide définitif sur la mortalité accidentelle liée à la pêche, mais une évaluation transparente, défendable et rigoureuse de la principale base de données probantes à l'appui de la prise de décisions concernant la mortalité accidentelle liée à la pêche. D'autres directives sur la façon d'utiliser les renseignements contenus dans le présent document sont fournies dans un document de recherche d'accompagnement du SCCS.

1 INTRODUCTION

Stock assessment methods for Pacific salmon (*Oncorhynchus* spp.) require estimates of total mortality to obtain accurate exploitation rate and stock size estimates. Total mortality includes both natural mortality and fishing-related mortality. The latter is composed of retained catch, plus any incidental mortality associated with fishing activities. Fishing-related incidental mortality (FRIM) includes mortality of fish that encounter fishing gear but are not captured (e.g., escape mortality), that are dead upon or die during capture but are not retained (e.g., on-board mortality), and that die after release (i.e., post-release mortality). Globally, FRIM has been recognized as a significant conservation concern for freshwater and marine fish, as well as other organisms (e.g., turtles and marine mammals). Research efforts have been devoted to quantifying the extent to which non-target organisms are impacted from fishing activities (e.g., bycatch; Hall and Mainprize 2005; Davies et al. 2009) and the subsequent fate of those organisms (e.g., Hall et al. 2000; Coggins et al. 2007; Wilson et al. 2014). The conceptual basis and mechanisms underlying FRIM are similar among fisheries sectors including commercial, aboriginal, and recreational fisheries (Davis 2002; Cooke and Cowx 2006; Cooke and Schramm 2007).

Fisheries and Oceans Canada (DFO) uses FRIM to help manage a variety of fisheries that target Pacific salmon. It has long been recognized that mortality prior to capture and mortality post-release are important to stock assessments of Pacific salmon populations (Ricker 1976). However, there are limitations to the current methods and information base used to generate estimates of different types of FRIM. These limitations include the variability in the time course for monitoring mortality after a fishing encounter, the lack of fishery context-specific information (e.g., water temperature), and the need for an efficient process to incorporate new research as it becomes available. For example, recent research by Raby et al. (2015b) indicates that longer-term (i.e., greater than 24 hours) post-release mortality rates are higher than those currently documented in DFO's Integrated Fisheries Management Plans (IFMPs) which are based mainly on 24-hour holding studies that were conducted prior to 2001. Additionally, recent studies relevant to other aspects of fishing-related incidental mortality have not yet been incorporated into current estimates of mortality used by DFO Fisheries Management and Stock Assessment.

Improved estimates of FRIM will reduce the uncertainty in predicting the impacts of different fisheries. An improved understanding of factors that impact FRIM will aid in the post-season accounting of both natural and fishing-related mortality. In addition, the evaluation of all types of non-retention-related mortality will improve Canada's commitment to quantify total mortality in the Pacific Salmon Treaty.

Fisheries Management has requested, through the Canadian Science Advisory Secretariat (CSAS) process, that Science Branch conduct a review of the available literature pertaining to factors relevant to FRIM of Pacific salmon, and provide recommendations on a process to derive and/or modify current estimates of FRIM rates for use in the assessment and management of Pacific salmon fisheries. This request has been cleaved into two separate research documents. This research document is the response to the first part of the request; it will focus on management's need for an improved understanding of the factors related to fish mortality and develop tools to help distill the mortality information using a fish-centric approach. The second research document (Patterson et al. 2017) will use the information gathered in this paper and continue to develop tools and guidance for arriving at FRIM estimates. Additional background information on the myriad of current uses of FRIM estimates will be provided in the second document. The objectives, as described in the Terms of Reference, to be covered in this research document are as follows:

1. Identify and discuss potential impacts of key factors that can influence FRIM for Pacific salmon.
2. Conduct a comprehensive review of the primary and grey literature that contains documented evidence (e.g., mortality rates) of FRIM for anadromous salmonids.
3. Identify uncertainties and knowledge gaps in the information that is currently available to inform estimates of FRIM for Pacific salmon.

The objectives, as described in the Terms of Reference, that were covered in the second research document are as follows:

4. Provide guidance with respect to a process to derive (or update existing) FRIM rates (or range of rates) for Pacific salmon by species, gear type, location, and/or other factors deemed relevant to various fisheries (where possible and appropriate).
5. Provide guidance with respect to the future incorporation of new information and research on FRIM for Pacific salmon.

The overall objectives of this project are to provide an evaluation of the key factors influencing FRIM for Pacific salmon, and to provide recommendations on a process to derive and/or modify current estimates of FRIM for use in the assessment and management of Pacific salmon fisheries. Figure 1 provides the overall project design to show how the two research documents connect. Science advice that arose from the CSAS Regional Peer Review of this project is available in the form of a published Science Advisory Report (DFO 2016) for consideration in managing Pacific salmon fisheries and application in relevant Pacific salmon stock assessments.

The scope of the above work is focused on all fisheries that are directly targeting Pacific salmon within the Pacific Region. However, information from other types of fishing and other fish species will be used when necessary to augment our understanding of FRIM. We recognize that there are significant challenges with inconsistent use of terminology associated with FRIM. We have tried to clearly define the terms we have used, and where possible, we have referenced them. A glossary to help deal with some of the more commonly used terms has been included before the references.

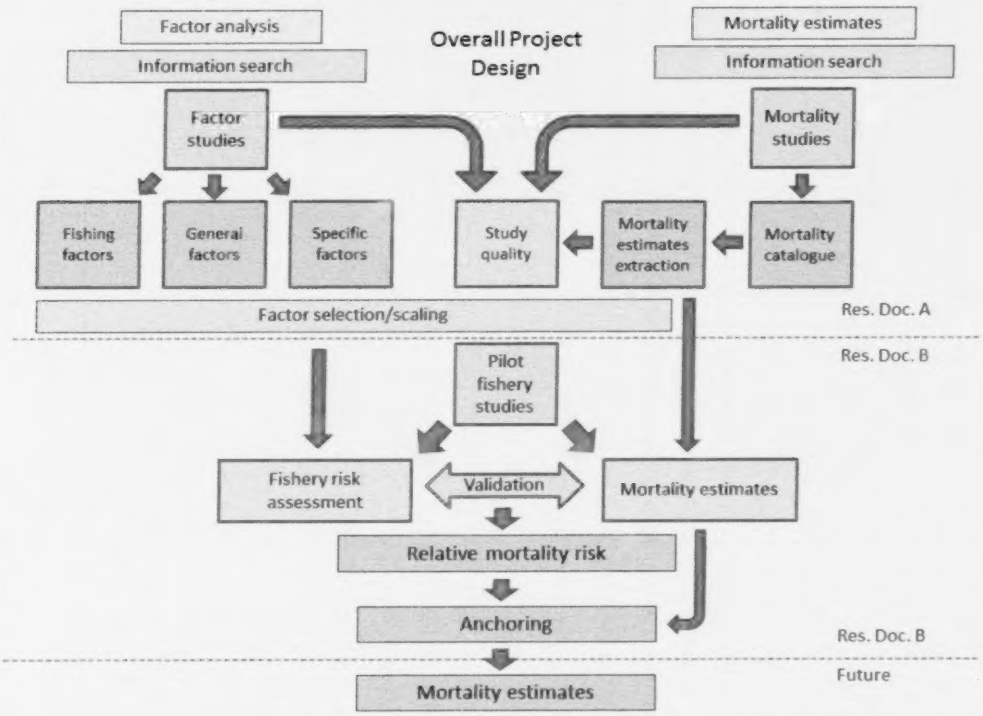
Factor analysis
Information search
Overall Project Design
Mortality estimates
Information search
Factor studies
Mortality studies
Fishing factors
General factors
Specific factors
Study quality
Mortality estimates extraction
Mortality catalogue
Factor selection/scaling
Res. Doc. A
Res. Doc. B
Pilot fishery studies
Fishery risk assessment
Validation
Mortality estimates
Relative mortality risk
Anchoring
Res. Doc. B
Future
Mortality estimates

Figure 1. The overall project design that connects the two Canadian Science Advisory Secretariat (CSAS) research documents (Res. Doc. A refers to this document; Res. Doc. B. refers to Patterson et al. 2017). Future work to arrive at updated mortality estimates for use in the assessment of Pacific salmon fisheries is still required. The research documents are summarized in DFO (2016).

1.1 CONCEPTUAL APPROACH TO UNDERSTANDING FISHING-RELATED INCIDENTAL MORTALITY

There have been several major reviews conducted to determine mortality rates associated with different fishing activities that are relevant to salmon fishing in the Pacific region (e.g., Ricker 1976). These reviews have primarily focused on trying to link specific fisheries to direct estimates of mortality. Such reviews were also focused on specific salmon species, specific locations (e.g., marine only; Cox-Rogers et al. 1999), and on specific gear types (e.g., hooking mortality; Hühn and Arlinghaus 2011). Similarly, there have been thorough reviews on factors that contribute to different components of FRIM (e.g., Davis 2002; Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007). Both factor reviews and mortality reviews were normally focused on specific mortality outcomes, such as post-release mortality, and not on total incidental mortality. The papers that focused on mortality estimates did mention key factors and the factor papers did provide examples of mortality estimates (e.g., Raby et al. 2015b). However, we are not aware of any comprehensive review that has considered all major fishing types (gear/method variants) for Pacific salmon in both marine and freshwater environments, and that covers all aspects of mortality associated with a fisheries encounter. Given the shear breadth of information that is potentially available on this broad subject, we have directed our efforts to locating sources of information and processes for evaluating them. This means, the information herein is not meant to be an exhaustive evaluation of the topic, but rather a systematic, in-depth analysis that will form the evidence base for decisions regarding FRIM. To this end, we have chosen a fish-centric approach that first focuses on understanding factors that drive FRIM and then on interpreting and extrapolating from available mortality evidence found in the literature. The critical evaluation of the mortality estimate literature will be informed by the knowledge gathered on key FRIM factors; study reliability and relevance will also be informative. The conceptual approach as it matches to each chapter of this document is depicted in Figure 2.

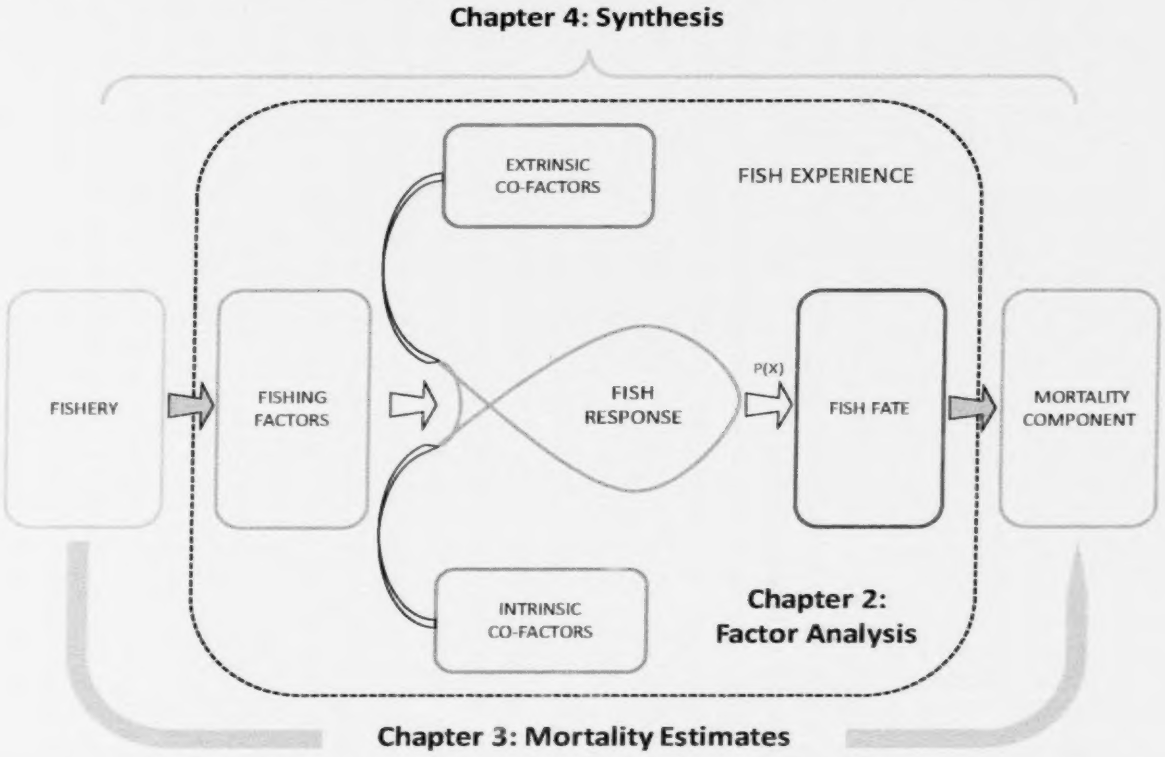

Figure 2. A diagram outlining the connection among the three remaining chapters of this research document. Chapter 2 focuses on understanding the fish response in relation to the duration of exposure to key fishing factors and the role that intrinsic and extrinsic co-factors may play in determining the fate of fish. Chapter 3 collects evidence on different components of fishing mortality relevant to specific salmon fisheries. And, Chapter 4 synthesizes the understanding of factors driving mortality with the mortality estimates extracted from the literature.

The first project objective is covered in Chapter 2 and herein referred to as the factor analysis. The factor analysis provides a general examination of the fish literature to gather information on the fishing factors and co-factors (intrinsic/extrinsic) that are associated with FRIM. The focus is on the mechanistic understanding of FRIM. As such, the impact of a factor will be linked to mortality via fish response. From this, the strength and consistency of evidence that links each fishing factor or co-factor to mortality will be identified and used as advice regarding the confidence of using specific factors in an assessment of mortality risk in Chapter 4. This will provide a flexible platform to deal with future combinations of factors as they are identified.

The second project objective is covered in Chapter 3 and herein referred to as the mortality evidence catalogue. The goal of this chapter is to comprehensively catalogue information on mortality estimates relevant to FRIM for Pacific salmon. Emphasis will be placed on the methodology developed to gather mortality evidence to address the request for a process to update our FRIM understanding as new research becomes available.

The third project objective is included in Chapter 4. This chapter consists of a synthesis of the factor analysis and the mortality estimates in mortality evidence catalogue. This involves examining the consistency between factors that are known to drive mortality derived from the general literature and the mortality estimates that were extracted from specific studies examining FRIM in salmon. We generated a short list of fishing factors that could be used to describe specific gear and method variants related to FRIM. In addition, we identified five key risk factors that can be scored against a risk of mortality for use in assessments of risk. This examination exposes the uncertainties and gaps associated with the current knowledge base. Finally, a list of key recommendations that relate to both future research efforts and processes of gathering additional evidence related to FRIM is provided.

The ultimate utility of the information and processes developed herein will depend on the applicability to current stock assessment and fisheries management structures; this is the purpose of the accompanying research document (Patterson et al. 2017). Connecting the factor analysis with the mortality estimates in a way that is useable for management purposes first requires the disaggregation of a fishery into an understanding of the fishing-related factors that are relevant to the fish experience, response, and ultimately fate. Second, it requires the conversion of fish fate into mortality components that can be used by stock assessment and fisheries management (see red arrows on Figure 2).

1.2 FISHERIES AND MORTALITY COMPONENTS

There is no standard reference for defining a fishery in the Pacific Region. However, there are common elements in most descriptions and they include: the primary licence holder group or individual (i.e., Commercial, Recreational, First Nation); the location of the fishery (i.e., management area or water body); the timing of the fishery (e.g., seasonal openings); the primary capture gear used (e.g., seine, rod and reel); and the target species of interest. The level of detail to describe a fishery (i.e., fishery descriptors) will depend on how the mortality estimates are used. For example, in the DFO Integrated Fisheries Management Plan (e.g., DFO 2015), the level of detail provided for post-release mortality estimates is general and typically applies to major generic fishing types and is not well defined by space or time. In contrast, the more specific level of detail for estimating FRIM for post-season stock assessments purposes (e.g., fisheries that may intercept Interior Fraser coho salmon (*O. kisutch*)), can be evaluated at the level of method variation (e.g., bottom-bouncing), river reach (e.g., Port Mann to Mission Bridge), and a specific time frame (e.g., August 2010). For the purpose of this review, we have focused on those fishery descriptors that are potentially relevant for understanding estimates of FRIM at both the general and specific level.

Similarly, there are no standard guidelines to define the different components of FRIM that will work for all potential uses of mortality estimates. As such, we have a chosen to follow the general categories as defined by the International Council for the Exploration of the Sea (ICES; 2004). However, we further disaggregate the *discard mortality* category used by ICES into three separate sub-categories: on-board mortality, $\leq$ 24 h post-release mortality, and > 24 h post-release mortality. The $\leq$ 24 h post-release mortality was delineated to reflect the current estimates used in the IFMP, which are based primarily on short-term holding studies. To avoid confusion, the above terms, called mortality components herein, will be used wherever possible when describing different aspects of FRIM. The mortality component definitions used are as follows:

Avoidance mortality: Mortality of fish that encounter fishing gear but actively avoid the gear without direct physical contact, resulting in fatigue and stress (e.g., gear avoidance through difficult passage areas).

Escape mortality: Mortality of fish that actively escape after contact with fishing gear prior to landing (e.g., escape from a hook or gill net).

Depredation: Fish that die as a result of predators directly removing fish from fishing gear during the capture process; this does not include the predation of released fish.

Drop-out: Fish that die and drop out of the fishing gear prior to landing (e.g., drop-out of gill nets).

On-board mortality: Mortality of captured fish; this observable mortality includes fish that are dead on landing or die on board prior to release (e.g., during sorting or in holding tanks).

Short-term post-release mortality ($\leq$ 24 h): Mortality of fish that occurs up to 24 hours after released alive.

Delayed post-release mortality (> 24 h): Mortality of fish that occurs more than 24 hours after released alive.

We have included a glossary to help remove some of the confusion regarding definitions. The application of this information to models that use mortality estimates will vary depending on their use in stock assessment or fisheries management models. The simple approach we provide is to include all the pre-capture mortality components into a single "drop-off" category, a "retained" category for retained catch, and a "release" mortality category for fish that die on board or post-release. To use the drop-off category, an estimate of encounter rates is required. However, that is beyond the scope of this project. Patterson et al. (2017) provides more background on how mortality estimates are used and some clarity with respect to the terms just mentioned. An overview of the terms used to describe the central axis of this approach that links the different fishing activities, encounter events, fish responses, and fish fate, with the mortality components used in this report is provided in Table 1 and Figure 3.

Two additional mortality components identified by ICES (2004) that are not covered by this review are ghost fishing mortality and fish mortality caused by habitat destruction from the fishing gear. The latter is unlikely for salmon-directed fishing in Canada, and the former may be an issue for some net fisheries, but there is no information currently available in the literature to support inclusion in this review.

Table 1. An overview of the definitions and relationship of terms used in the report in connecting fishing activities, with fish-centric responses and corresponding management categories for mortality. Each row represents a unique combination of fishing actions and the common terms that describe the encounter, the type of fish response that can occur (i.e., stress, injury, behavioural alteration and infection), the period of the response (i.e., acute or chronic), the associated fish fate (predation, latent mortality, acute mortality), the type of mortality component, the risk category, and the mortality rate use (see Patterson et al. 2017 for details on management terms). Full definitions can be found in the glossary.

	Fishing Process		Fish Response			Management Terms		
Event	Action	Encounter	Acute	Chronic	Mortality	Mortality Component	Risk Category	Mortality Rate Use
Capture	Deploying	Avoidance	Stress	Behaviour	Predation	Avoidance	Drop-off	NCM
	Deploying	Avoidance	Stress	Behaviour	Latent	Avoidance	Drop-off	NCM
	Capturing	Escape	Stress	-	Acute	Escape	Drop-off	NCM
	Capturing	Escape	Stress	Stress	Latent	Escape	Drop-off	NCM
	Capturing	Escape	Stress	Behaviour	Predation	Escape	Drop-off	NCM
	Capturing	Escape	Injury	Behaviour	Predation	Escape	Drop-off	NCM
	Capturing	Escape	Injury	-	Acute	Escape	Drop-off	NCM
	Capturing	Escape	Stress	Infection	Latent	Escape	Drop-off	NCM
	Capturing	Escape	Injury	Infection	Latent	Escape	Drop-off	NCM
	Capturing	Depredation	Injury	-	Predation	Depredation	Drop-off	NCM
	Capturing	Drop-out	Stress	-	Acute	Drop-out	Drop-off	NCM
	Capturing	Drop-out	Injury	-	Acute	Drop-out	Drop-off	NCM
Handling	Spilling	Release	Stress	-	Acute	Short-term	Release	PRM
	Spilling	Release	Stress	Stress	Latent	Delayed	Release	PRM
	Spilling	Release	Stress	Behaviour	Predation	Short-term	Release	PRM
	Spilling	Release	Injury	Behaviour	Predation	Short-term	Release	PRM
	Spilling	Release	Injury	-	Acute	Short-term	Release	PRM
	Spilling	Release	Injury	Infection	Latent	Delayed	Release	PRM
	Spilling	Release	Stress	Infection	Latent	Delayed	Release	PRM
	Sorting	On-board	Stress	-	Acute	On-board	Release	CM
	Sorting	On-board	Injury	-	Acute	On-board	Release	CM
	Retaining	Killed	Stress	-	Acute	Retained	N/A	N/A
	Retaining	Killed	Injury	-	Acute	Retained	N/A	N/A
	Reviving	Revival	Stress	-	Acute	On-board	Release	CM
	Reviving	Revival	Injury	-	Acute	On-board	Release	CM
Post-Release	Releasing	Release	Stress	-	Acute	Short-term	Release	PRM
	Releasing	Release	Stress	Stress	Latent	Delayed	Release	PRM
	Releasing	Release	Stress	Behaviour	Predation	Short-term	Release	PRM
	Releasing	Release	Injury	Behaviour	Predation	Short-term	Release	PRM
	Releasing	Release	Injury	-	Acute	Short-term	Release	PRM
	Releasing	Release	Stress	Infection	Latent	Delayed	Release	PRM
	Releasing	Release	Injury	Infection	Latent	Delayed	Release	PRM

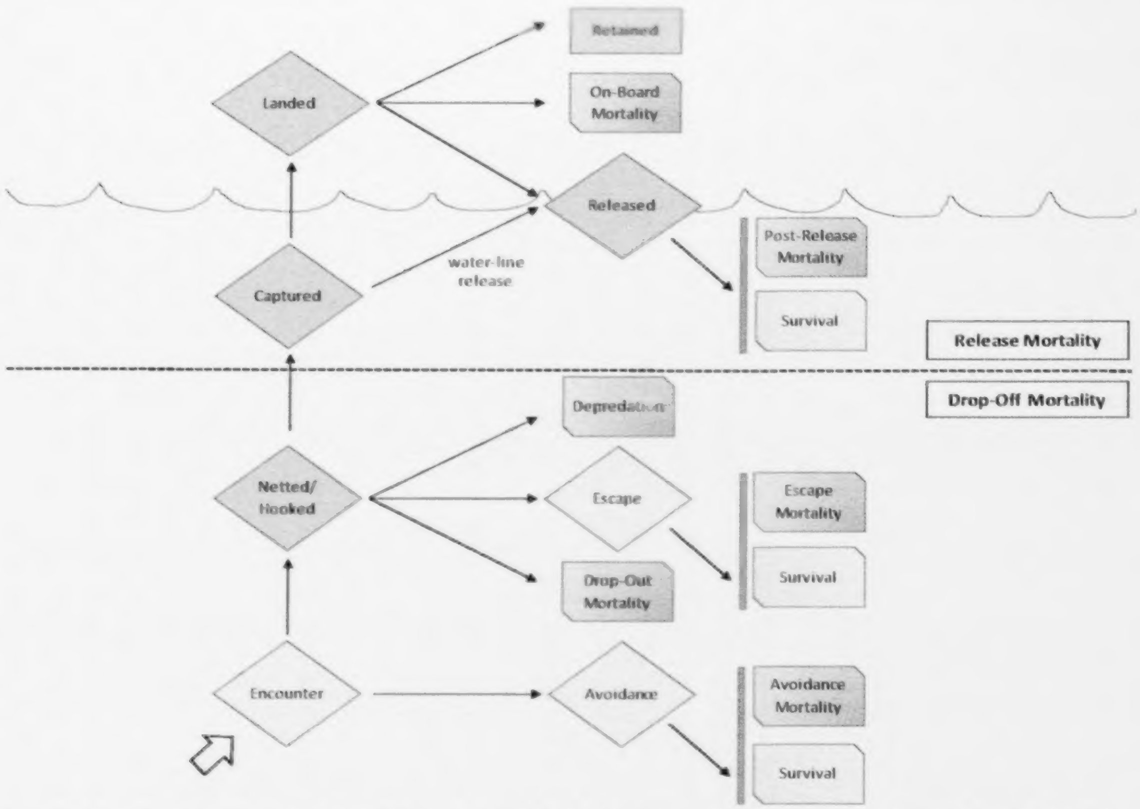
Retained
Landed
On-Board Mortality
Released
Post-Release Mortality
water-line release
Captured
Survival
Release Mortality
Drop-Off Mortality
Depredation
Netted/ Hooked
Escape
Escape Mortality
Drop-Out Mortality
Survival
Encounter
Avoidance
Avoidance Mortality
Survival

Figure 3. This diagram highlights the types of fate (all rectangles represent mortality or survival) resulting from a general fishing event. The diamonds depict the general progression of fishing activities (blue) and fish responses (yellow). The components of fishing-related incidental mortality (FRIM) are depicted by the red rectangles. The escape, avoidance and post-release mortality rectangles include acute and latent mortality (e.g., predation, infection). Note that the post-release mortality rectangle represents both the short-term (i.e., < 24 hours) and delayed (i.e., > 24 hours) mortality components, for a total of seven FRIM components. The black dashed line partitions these seven mortality components into two general mortality risk categories–release and drop-off mortality–for potential use in management (details in Patterson et al. 2017). Survival (green rectangles) can also include sub-lethal effects.

2 FACTORS RELEVANT TO FISHING-RELATED INCIDENTAL MORTALITY

2.1 INTRODUCTION

The main objective of this factor analysis is to identify and discuss the potential impacts of different factors that can influence the survival outcome of a fish resulting from a fishery encounter. To this end, we present a conceptual diagram of our fish-centric approach to understanding the effects of fishery encounters on fish response and ultimately fish mortality (Figure 4). The overall goal of this approach is to better understand how fishing factors that act in consort with extrinsic and intrinsic co-factors, can elicit different fish responses. Each component of this conceptual diagram is briefly described below; further details are provided in the subsequent sections of this chapter.

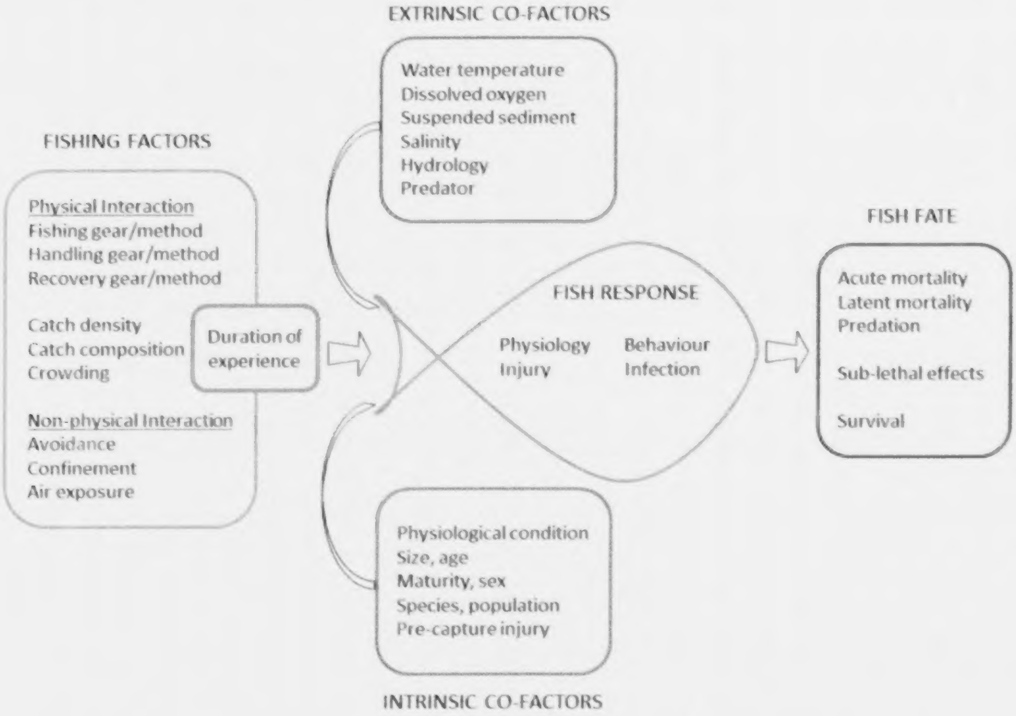
EXTRINSIC CO-FACTORS
Water temperature
Dissolved oxygen
Suspended sediment
Salinity
Hydrology
Predator
FISHING FACTORS
Physical Interaction
Fishing gear/method
Handling gear/method
Recovery gear/method
Catch density
Catch composition
Crowding
Duration of experience
Non-physical Interaction
Avoidance
Confinement
Air exposure
FISH RESPONSE
Physiology
Injury
Behaviour
Infection
FISH FATE
Acute mortality
Latent mortality
Predation
Sub-lethal effects
Survival
Physiological condition
Size, age
Maturity, sex
Species, population
Pre-capture injury
INTRINSIC CO-FACTORS

Figure 4. Conceptual diagram of factor analysis approach to understand the effects of fisheries encounters on fish mortality from a fish-centric perspective. The magnitude of the type of fish response (e.g., physiological stress, injury) to different fishing factors (e.g., gear/method variants) associated with the fish encounter are modified by the duration of the experience, and by intrinsic and extrinsic co-factors. This highlights the potential to understand the fate of a fish after a fishery encounter by evaluating information on the fish biology, the environment, and the duration of exposure to different physical and non-physical interactions.

Fishing factors: The type of interaction that a fish experiences during a fishery encounter will influence the biological response. Direct physical contact can lead to physiological stress, physical injury, and ultimately death (e.g., drop-out mortality). Physical contact can take place at some point during the capture event, and the type and intensity of contact will vary depending on the gear and method used (e.g., hook and line versus gill net). Further physical contact will take place during handling and any attempts at recovery, and will also vary by gear and method used (e.g., brailing versus ramping). An often-overlooked component of the physical interaction is the contact a fish can have with other fish during the capture and handling process. In net and trap fisheries, the catch size, density of catch, and species composition can influence the degree of physical contact during capture and handling. Fish can also experience non-physical interactions during the capture process and these interactions can also lead to physiological stress (e.g., during gear avoidance, and confinement). To be clear, all fishery interactions will elicit some level of physiological stress (i.e., exercise and struggling is inherent in all fisheries) and if there is physical contact it will result in some level of injury (e.g., hook puncture, dermal abrasion).

Duration of experience: The greater the amount of time a fish experiences a fishing-related stressor (either physical or non-physical), the greater the potential for a more severe physiological stress response (e.g., exhaustion). Similarly, the greater the amount of time a fish is in physical contact with fishing gear, the higher the probability of injury (and in some cases higher severity).

Fish response: Direct physical contact or the perceived threat of contact will elicit an acute physiological stress response. Upon contact, fish can become injured, contributing to additional stress. The inability to cope with either stress or injury can lead to acute mortality, behavioural modifications (e.g., impaired swimming ability), and/or infections. Changes in behaviour and disease development can reduce the future survival probability of a fish (e.g., whether it will be able to avoid a predator).

Intrinsic and extrinsic co-factors: Certain environmental conditions (e.g., high water temperatures) can modify the response of a fish to a fishing-related stressor. Similarly, the intrinsic condition of a fish can modify the response of a fish to a fishery encounter (e.g., fish size and gill net mesh size).

Fish fate: The fate of a fish following a fishing encounter can be categorized into five possible outcomes:

- Survival – A fish mounts a successful adaptive stress response and survives the fishing encounter with no change to their future fitness
- Sub-lethal effect – A fish survives the fishing encounter for the foreseeable future, but suffers sub-lethal effects that reduce their future fitness (e.g., reduction in growth or direct detrimental effects on reproductive development)
- Acute mortality – A fish dies during or shortly after the fishing encounter (e.g., within 24 h) from either an inability to recover from a severe physiological response (e.g., acidosis), or from a severe wound (e.g., exsanguination)
- Latent mortality – A fish dies days to weeks after the fishing encounter from the inability to overcome the stress, injury, or resulting infection
- Predation – A fish is preyed upon either during or after capture, contributing to both acute and latent mortality

For the purpose of this analysis, we are focusing on understanding factors that influence mortality. This is not meant to downplay sub-lethal effects (see review on sub-lethal effects by Wilson et al. 2014), and indeed, we have presented some information on sub-lethal impacts in both this factor analysis and the mortality estimate catalogue.

In this chapter, we first describe the methods used to list the factors that can influence mortality associated with a fishing encounter. Next, we describe, in general terms, the fish response to a fishery encounter as it relates to physiology, injury, behaviour, and infection, and the potential mortality outcomes associated with these responses. The final sections are dedicated to discussing fishing, intrinsic and extrinsic factors, and the potential utility of these factors in understanding FRIM. The information from this factor analysis can aid in the interpretation of studies that provide estimates of FRIM for Pacific salmon (e.g., Chapter 3). In addition, this information will be used to inform the selection of key factors relevant to the evaluation of mortality risk in a fishery (see Chapter 4) and the development of relative mortality risk ratings for different fisheries as it relates to FRIM (Patterson et al. 2017).

2.2 METHODS

The primary goal of the factor analysis is to summarize information on those factors that can influence the incidental mortality of anadromous salmonids after an encounter with fishing gear. To do so, we have created an interactive factor analysis repository tool to store and update relevant information. This tool was designed to accomplish the following objectives:

- Create an up-to-date information database on biological research related to FRIM
- Support the summarization of the extent of the science related to relevant factors
- Provide input on key factor information to be extracted from mortality estimate studies
- Identify knowledge gaps and ideas for future research

In addition, the structure of this information repository provides a platform to execute secondary searches of the relevant factor analysis literature, allowing users to target information at specified levels of interest

Our information collection strategy for creating the list of relevant factors included the assessment of major review articles and the solicitation of advice from subject area specialists within our research group (authors of this document), as well as supplemental searches of online databases. The last step was included to assess if factors had been overlooked or recently emerged. Next, we determined the extent that each factor was supported by the literature. Thomson Reuters Web of Science online database was used as the primary search engine to facilitate repeatable searches; we started using general search terms for basic search parameters, then switched to using more specific terminology in the advanced search parameters. Each search string was documented (see Appendix A) and numbered, and yielded a set number of results. The searches were not exclusive to anadromous salmonids in order to extend our reach for potential factors. To sort through each search result, articles were included or excluded based on the information in the title and abstract. For an article to be included at the title/abstract level, it had to mention the search terms in a relevant way (i.e., if a search component "salmon*" returned "salmonella" in the title, it was excluded). Those that were included were exported and entered into the factor analysis repository tool. The information recorded in the tool is coded in Appendix A and an electronic version of the tool is available upon request (David Patterson, DFO Science, Burnaby, B.C.) or through the Government of Canada's Open Data Portal (open.canada.ca/open-data).

From the list of compiled factors, authors were assigned to summarize the information relevant to their subject area speciality. The written factor summaries are a synopsis of the research papers identified in the repository tool as well as supplemental support from unpublished research, where necessary.

The summaries of evidence presented herein are based on the assessment of thousands of papers at the abstract and title level. However, we did not use a completely systematic search methodology; thus, the results do not represent a systematic review of all available evidence for each factor. Rather, it provides a representative overview of the current state of knowledge with respect to FRIM.

2.3 FISH RESPONSE TO FISHERIES ENCOUNTER

This section provides a detailed overview of the physiological stress response and injuries that can be caused by a fish's encounter with a fishery. The secondary changes in physiology, behaviour, and infection associated with the initial response to the encounter will also be examined in detail. For each response, a mechanistic link to mortality is discussed at different time scales, as well as sub-lethal outcomes. The connection to the specific mortality components used by management will come later during the discussion of the major factors.

2.3.1 Physiological Response

Fisheries-related physiological stressors include perceived (i.e., flight response) or direct physical contact with fisheries gear followed by entanglement (e.g., net confinement, crowding) or hooking (e.g., hook and line), landing, handling, and air exposure associated with removal from gear in both net and line fisheries (summarized in Davis 2002). As a primary response to a fisheries-related stressor, catecholamines and corticosteroids are released which in turn initiate the secondary stress response at the tissue-level (Barton 2002). The secondary response includes osmoregulatory, ionic, metabolic, and cellular responses to stress (Wendelaar-Bonga 1997). The cellular suite of responses helps organisms to temporarily tolerate or counteract stress, or remove damaged cells through apoptosis (Kültz 2005). Thus, changes in gene expression can be linked with various fishing-related stressors in salmon (Krasnov et al. 2005; Donaldson et al. 2014).

Fisheries capture involves interactions between the stress response and exercise physiology, and these interactions have been well studied in salmonids (Wood 1991; Milligan 1996; Kieffer 2000). For maturing Pacific salmon, the basic physiological response and recovery patterns of many secondary stress indicators are relatively consistent among species; however, the magnitude of the response and duration of recovery is likely to vary across species, likely due to variation in intrinsic co-factors such as differences in body size or state of reproductive maturation (Raby et al. 2013; Donaldson et al. 2014; Raby et al. 2015b). Regardless of species, sex-specific differences in physiological metrics exist, for example, in circulating plasma cortisol, which may drive sex-specific differences in survival following fisheries encounters (Raby et al. 2015a). Within species population-differences are also apparent, a finding that holds true for both response to fisheries-related capture stress (Donaldson et al. 2012) and thermal optima for aerobic scope (Eliason et al. 2011), suggesting that the interactive effect of both fisheries capture and temperature may have population-specific outcomes.

Previous work developed from comparative physiology studies on exercise stress has highlighted two important factors relevant to understanding how capture affects fish. First, the type and duration of stressor influences the level of stress incurred by fish (Wood 1991; Kieffer 2000). For example, the duration of capture is typically proportional to the magnitude of physiological response (e.g., Gustaveson et al. 1991; Chopin et al. 1996) and the magnitude of stress, including interactive effects such as temperature and air exposure, can result in impaired ventilation, equilibrium loss, and mortality (Gingerich et al. 2007). Second, physiological disturbances demonstrate typical recovery profiles, which if severe or prolonged, may lead to mortality (Black 1958, Wood et al. 1983). There is a context-specific nature of fisheries effects, where different capture gears and methods can differentially influence physiological responses and survival (Donaldson et al. 2010), and extrinsic co-factors such as environmental conditions may exacerbate mortality (see section on temperature). Intrinsic co-factors such as sex-specific (Robinson et al. 2013; Gale et al. 2014) and population-specific (Donaldson et al. 2010; 2012) differences are also commonly observed in terms of physiological responses and survival following capture (reviewed in Raby et al. 2015b). Extrinsic and intrinsic co-factors can influence the magnitude of response to the capture event and the likelihood of physiological recovery and survival. The physiological metrics that are typically measured can each interact with nearly all identified intrinsic and extrinsic factors. Temperature is the major interacting factor (Raby et al. 2015a; reviewed in Gale et al. 2013). Injury, disease, and behaviour can each influence physiology and vice versa. Each of these factors may directly or indirectly lead to a lower probability of survival following a fisheries encounter.

Fish rely on anaerobic pathways during exhaustive exercise and hypoxia, stressors that typically occur during fisheries capture. Specifically, oxidative pathways are insufficient to meet the oxygen requirements to respond to the stressor and thus, anaerobic pathways are required. Fisheries-related capture and handling procedures can result in various durations of hypoxia from air exposure, ranging from seconds to several minutes and resulting in a hypoxic stress response (Ferguson and Tufts 1992; Sloman et al. 2001). Hypoxia may also occur in net fisheries if ventilation is physically restricted during net retrieval, sorting, and handling, or, in the case of shoreline seine fisheries, localized oxygen depletion. While exhaustive exercise alone contributes to acidosis, air exposure further reduces plasma pH (Ferguson and Tufts 1992). Post-exercise ventilation rates may be reduced at higher temperatures, resulting in reduced gas exchange (Gale et al. 2011). Air exposure can contribute to increases in blood lactate and glucose as gas exchange is inhibited due to a collapse of gill lamellae and a reduction of gill surface area (Arends et al. 1999; Cook et al. 2015). These events may independently elicit the general stress response but the stressors are likely cumulative, since at this stage the stress response timecourse has already begun (Ferguson and Tufts 1992).

The recovery process functions to restore homeostasis while incurring a minimal additional metabolic cost (Wood 1991). The time required to clear metabolites from the blood and restore muscle energy stores may limit subsequent performance, and recovery rate will determine the potential frequency of maximal performance (Milligan 1996). Stress and prolonged recovery may lead to tertiary consequences, including delayed mortality (Black 1958; Wood et al. 1983). Excess post-exercise oxygen consumption (EPOC) refers to the increased oxygen consumption that occurs during recovery from exercise or hypoxia to re-establish homeostasis following anaerobic activity (Lee et al. 2003). EPOC is a critical component of recovery since it encompasses the increased oxygen required to restore oxygen, glycogen, and high energy phosphate stores and to restore metabolite and ion-osmoregulatory balance (Gaesser and Brooks 1984; Scarabello et al. 1992). Recovery from exhaustive exercise and hypoxia has ecological outcomes since swimming performance may be limited during the time required to return to routine oxygen consumption, clear blood metabolites and restore muscle energy stores (Milligan 1996); though Pacific salmon have a remarkable capacity for swim performance even before fully recovering physiologically from a previous exhaustive exercise event (Eliason et al., 2013).

The inability to fully recover between bouts of exhaustive exercise feeds directly into the importance of the magnitude of the stressor and impact it can have on physiological parameters. For example, if plasma lactate loads exceed a threshold of 10-13 mmol/L then repeat swim performance is impaired (Stevens and Black 1966; Farrell et al. 1998). In time, individuals may be able to physiologically recover from the fisheries encounter but pre-existing intrinsic factors, chronic stress, prolonged recovery periods, or interactions with extrinsic factors may lead to sub-lethal consequences and latent mortality. Existing condition and external environment can influence the magnitude of response to the capture event and the likelihood of physiological recovery. Mortality can therefore be mediated by extrinsic and intrinsic co-factors and if homeostasis cannot be recovered (Schreck 2000) the stressor can lead to tertiary outcomes including reduced survival (Black 1958; Wood et al. 1983). Direct and indirect mortality are common endpoints in studies designed to quantify post-release mortality from both commercial and recreational fisheries.

Fisheries-related mortality is commonly categorized as immediate, short-term, or delayed (Pollock and Pine 2007). Immediate mortality occurs at the time of capture where the fish is either dead upon landing or dies prior to or during release. Short-term mortality may be observed within hours of the capture event (usually up to 24 h) and is commonly linked with injury or an inability to recover from capture stress (Muoneke and Childress 1994). Fish respond to the capture-stressor by mounting a stress response (i.e., primary, secondary, tertiary response; Barton 2002). Post-capture, if homeostasis cannot be recovered (Schreck 2000) the stressor can lead to tertiary outcomes including reduced survival (Black 1958). A number of laboratory studies have identified that exhaustive exercise stress, which is analogous to extreme fisheries-related capture stress, can often lead to mortality in the minutes or hours post-stress if individuals were unable to mount a physiological recovery (Wood et al.1983). Delayed mortality occurs days or weeks following release (Pollock and Pine 2007), often making it difficult to quantify. However, recent studies on Pacific salmon have found that the duration and magnitude of fisheries capture results in a higher magnitude physiological stress response and also a lower probability of survival (Donaldson et al. 2010; 2011).

There is now strong correlative evidence that delayed mortality is associated with capture stress. Donaldson et al. (2011) found that the most physiologically stressed individuals were also the least likely to survive to spawning grounds. Stock-specific differences in post-release survival have also been observed (Donaldson et al. 2012). The stressor alone may not be the mechanism of mortality, but the inability to recover, particularly due to interactions with other co-factors such as injury or disease, may be the causal factor. While mortality results in direct loss of fitness for Pacific salmon, indirect fitness costs remain a high possibility, as reproductive hormones may be depressed following exposure to a stressor (Donaldson et al. 2010; 2014) which has the potential to affect the trajectory of maturation and lead to sub-lethal reproductive effects. In addition, the higher the magnitude of the stressor can result in a greater physiological stress response and a higher likelihood of mortality (Donaldson et al. 2013). Overall, there is strong evidence for the context-specific, sex-specific, and population-specific differences in delayed mortality associated with release fisheries (Donaldson et al. 2012; 2014; Raby et al. 2013; Raby et al. 2015b).

In summary, the physiological stress response mounted by a fish in response to a capture or handling-stressor is part of an adaptive process aimed to restore homeostasis. However, in instances where the magnitude and duration of the stressor overcomes the fish's ability to cope, acute mortality may occur (e.g., acidosis from exhaustion). More often, the time course required to recover from the initial capture stress, and any associated injuries, can lead to further impairment and ultimately delayed mortality. Delayed mortality can be a complex interaction of injury and stress, leading to infection, and reflex impairment leading to behavioural changes affecting predation risk.

2.3.2 Injury

All instances of capture and handling of fish will cause some degree of physical injury, ranging from mild (e.g., loss of mucus) to more severe (e.g., broken skin, damaged internal organs) (Davis 2002). The nature and severity of injury is often associated with the type of capture and the subsequent handling technique that is employed. For instance, fish captured in gill nets are likely to receive deep flesh wounds and fishers often insert their fingers under the operculum to ease the removal of the entangled fish. This can be contrasted with seines, which corral but do not entangle fish, often causing less damage to the dermis and from which fish can be easily released.

Level of injury associated with capture may be predictive of survival. Severe injury at capture may cause immediate mortality, typically through severe blood loss from gill arch damage. Indeed, a major source of acute mortality associated with injury is from excess blood loss. Blood loss can result from severe gill injuries typically associated with removal from nets or from hitting major blood vessels during hooking events. Severe blood loss from gill injuries can have large effect on mortality (Ng et al. 2015). In cases where immediate mortality does not occur but fish incur large injuries (i.e., bleeding wounds), the likelihood of survival to spawning is decreased; bleeding was a significant predictor of post-release mortality in a recreational Chinook salmon (*O. tshawytscha*) fishery, where 21.4% of bleeding fish died post-release compared to 4.3% in non-bleeding fish (Bendock and Alexandersdottir 1993). Similarly, wounds to vital organs (eyes, gills, or tongue) decreased survival dramatically, particularly for small individuals (Bendock and Alexandersdottir 1993). It is reasonable to assume that gear types and handling practices that are more likely to cause bleeding wounds or injury to vital organs will increase the likelihood of FRIM. For example, two years of radio telemetry studies in the lower Fraser River, fish captured by gill net consistently had the higher mortality rate throughout the remaining migration within 1-2 days following capture (Art Bass, UBC, Vancouver, B.C., unpublished data). This is contrasted with fish captured by beach seine which were lost at a steadier rate throughout the remaining migration. Injuries that do not cause visible bleeding or open wounds may impact survival, but to a lesser extent. For example, level of abrasion in trawl net fisheries for as a result of net contact and/or crowding was significantly related to increased post-release mortality in Walleye Pollock (*Gadus chalcogramma)* but not Pacific halibut (*Hippoglossus stenolepis)* (Davis and Ottmar 2006).

Mechanisms causing mortality as a result of less severe injury are less direct than severe injuries. Generally, the loss of mucus covering has complex consequences for fish survival. Mucus covering the skin, scales, stomach, and gills of fish is the first defense against invading pathogens (Fast et al. 2002). Mucus is part of the innate immune response and entraps microorganisms and continuously sloughs, inhibiting colonization of the integument (Roberts 2012). Mucus contains lysozymes, enzymes that destroy the cell walls of some bacteria (Dalmo et al. 1997), and antibacterial proteins capable of forming pores in the membranes of invading pathogens (Ebran et al. 2000). Increased secretion of mucus by the mucosal epithelium was associated with the presence of monogeneans in carp (Prost 1963) and American eel (Chan and Wu 1984), and mucus cell abundance increased with infection of *Ichthyopthurius multifiliis* (Ventura and Paperna 1985). Consequently, any fisheries activity that disrupts the mucus coat has the potential to increase probability of infection. For example, infection by *Vibrio anguillarum* was facilitated by experimental removal of mucus from Atlantic salmon (*Salmo salar*) (Svendsen and Bøgwald 1997). Any contact with fishing gear (e.g., nets, traps, hooks, boats) or handling gear (boat deck, brailer, sort box, hands, glove, gaff) are expected to remove mucus and limit the ability to defend against pathogens.

The most external layer of fish skin provides a physical seal between a fish and its surroundings and expresses a great variety of antimicrobial peptides (Rakers et al. 2010). Svendsen and Bøgwald (1997) found that Atlantic salmon exposed to *Aeromonas salmonicida* following experimental wounding were more likely to become infected than control fish. Research suggest that skin plays an important role in maintaining osmotic balances in fish by preventing free exchange of ions with the environment (Olsen et al 2012). If this is the case, physical damage resulting from capture in iso-osmolar environments (estuary) should have a less severe impact than in sea or freshwater (Rosseland et al. 1982). For Pacific salmon, skin thickens dramatically as the migration progresses (Robertson and Wexler 1960), resulting in greater resistance to damage by nets and handling (Art Bass, UBC, Vancouver, B.C., personal communication). This has the potential to explain low mortality rates for simulated capture events for Pacific salmon tested on maturing fish at or near the spawning grounds (Donaldson et al. 2012; Raby et al. 2013).

As the integument and its protective mucus covering provide the first line of defense in the salmon immune system, damage revealing sub-dermal tissue can have important consequences for infection and survival (Thompson et al. 1971; Press and Evensen 1999; Jensen et al. 2015). Baker et al. (2014) found that 6 to 44 % of sockeye salmon (*O. nerka*) that arrived at spawning grounds in 9 river systems (Bristol Bay, AK) over five years had injuries indicative of gill net non-retention. Over half of these damaged fish reached spawning grounds but failed to reproduce and many presented fungal infections (Baker and Schindler 2009). Experimentally descaling herring to study purse seine non-retention, Olsen et al. (2012) found that mortality was 10-60% after one week and that descaled fish experienced a loss of osmoregulatory ability.

There are three areas of research that are likely underrepresented in the literature. The first is bruising and internal organ damage. Simulations of gill net entanglement have been conducted to test for constrictions associated with gill netting (Kojima et al. 2004). These results highlight the potential physiological consequences associated with severe constriction. Second, is wound healing capacity and its interaction with maturity and salinity. Pacific salmon are commonly observed on the spawning grounds with major wounds that have been healed. However, it is unclear whether these wounds were inflicted and healed in freshwater or simple legacy events from saltwater residence. Given the interaction of injury, infection, and water temperature in fresh water it would be important to elucidate the ability of maturing salmon to heal in freshwater (Jensen et al. 2015). The third area is also related to the interaction of injury and water temperature. It is commonly observed for injured fish to stage in cool water refugia during upstream migration, especially in warm temperature years (Macdonald et al. 2000). Comparatively little is known about injury and subsequent fish behaviour in salmon (see Nguyen et al. 2014).

2.3.3 Behavioural Response

Behavioural changes resulting from fisheries capture could result in failed reproduction or mortality either directly (e.g., predation) or indirectly (e.g., migration delays). An area of particular vulnerability is during the return spawning migration. En-route migration behaviour involves a certain level of plasticity that maximizes the likelihood of reproductive success. Migrating salmonids will adjust their migratory timing to avoid temperatures above their thermal optima by either migrating earlier (steelhead – *O. mykiss*); Robards and Quinn 2002) or later (sockeye salmon; Cooke et al. 2009; Atlantic salmon, Juanes et al. 2004), or adjust migratory path to find thermal refugia (Chinook Salmon, Berman and Quinn 1991; sockeye salmon; High et al. 2006). In cases where hydrological conditions are unfavourable, individuals will conserve energy by utilizing low-velocity regions within the water column (Hinch and Rand 2000; McElroy et al. 2012), or if high-velocity areas are unavoidable, engage in anaerobic burst swimming to rapidly move through these areas and reduce exposure to such conditions (Burnett et al. 2014a). Because semelparous migrations occur on a fixed energy budget, any additional energy demands have the potential to negatively affect migratory (Rand et al. 2006) and reproductive success (Braun et al. 2013).

During fisheries events intrinsic factors (e.g., species, size, ontogeny, injury, disease state, and physiology) can interact to influence fish behaviour. Such variation in behaviour can influence the probability of capture and probability of survival post-release. In addition, behavioural response to extrinsic factors, such as water temperature or velocity, can influence behaviours that may affect probability of capture and/or mortality. Impaired reflexes that are a direct result of injury, air exposure, and exercise and stress physiology have been used with varying levels of success to predict survival for fish captured in recreational (Cooke et al. 2013; Brownscombe et al. 2013), trawl (Davis 2010), gill net (Raby et al. 2013), and seine fisheries (Farrell et al. 2008). More complex behaviours associated with likelihood of capture and survival post release are covered below.

Variation in migratory behaviour influences the probability an individual will interact with fisheries. Because fishing effort is often spread spatially and temporally across salmonid migrations, the longer a fish spends within an active fisheries area, the greater the likelihood that fish will be captured. Consequently, any factor that causes alteration to migration behaviour such as fall back (e.g., Donaldson et al. 2012), or slowed migration rate, can increase the probability a fish will encounter fisheries and be re-captured if more time is spent in active fishing areas.

Fallback in salmonids is believed to naturally occur during spawning migrations for several reasons, including waiting for appropriate conditions (Thorstad et al. 2003; Holbrook et al. 2009), disorientation due to variable hydraulic conditions (Naughton et al. 2006), and navigating obstacles such as dams or waterfalls (Matter and Sandford 2003). Fall back associated with behavioural impairment that occurs as a result of fisheries are extremely difficult to quantify because any tracking of fish post-release requires tagging (Frank 2009). However, Frank (2009) found that the physiological response of anadromous alewife was similar in handled fish that were tagged and untagged, and physiological response is often correlated to behavioural response in fishes (Frank 2009; Farrell et al. 2001b; Raby et al. 2013) suggesting that behaviour from tagging studies may be similar to what would be expected in fish handled and released from fisheries. Fallback was found to occur in 31% of Atlantic salmon released from recreational fisheries (Thorstad et al. 2007) and be more severe for gill-net caught salmon compared to angled salmon (Mäkinen et al. 2000), and Nguyen et al. (2014) demonstrated depressed migration rate in injured sockeye salmon released from a gill net fishery simulation. As Pacific salmon migrate on a fixed energy budget, any fall back as a consequence of fisheries may deplete energy reserves necessary to reach spawning grounds.

Behavioural response of fish immediately upon capture is dependent on the type of fisheries gear that is employed. Generally speaking however, fish will encounter the gear and exhibit evasive behaviours including hesitation, reverse swimming, and burst swimming (Chopin et al. 1996). The duration of time spent burst swimming and/or struggling is dependent on several factors including amount of tension present in the fisheries gear, whether other fish are present in the net at time of capture, and aerobic scope of the fish upon capture (Chopin et al. 1996)

Behaviour of released exhausted fish can be impaired immediately post release (e.g., Brownsombe et al. 2014b). Behaviour of released pike (*Esox lucius*) was significantly related to the duration of air exposure one hour post release (Arlinghaus et al. 2009) – fish with 300s of air exposure took longer to initiate first movement post release, and there was a trend of decreased swimming activity with increasing air exposure duration; however, fish recovered from the differential effects of air exposure such that there was no significant difference in behaviour after two days. Fish with impaired behavioural response are at greater risk to predation, as demonstrated in bonefish (*Albula vuples*) consumed post-release by lemon sharks (*Negaprion brevirostris*) (Cooke and Philipp 2004; Danylchuk et al. 2007). Similar response can be expected from fish that have escaped gear as a result of similar physiological imbalance and physical injury (Chopin and Arimoto 1995). In commercial fisheries where predators have adapted to associate fishing boats with congregations of potential food sources, opportunistic predation of released and/or escaped fish is a serious concern.

Foraging behaviour can be altered by fisheries interactions. Stålhammar et al. (2012) found that pike released from an angling and 60 second air exposure trial had impaired foraging capabilities compared to prior to the trial, however, this effect was dampened when fish were released into arenas containing similar sized conspecifics. These sub-lethal effects are rarely identified (Wilson et al. 2014).

There is potential to use the recent work on reflex impairment scores (e.g., Reflex Action Mortality Predictors or RAMP assessments) to help describe responses to fisheries capture, even though they were designed to be predictors of fate, and not descriptors of response (Davis 2005; 2007; 2010). RAMP assessments are essential vitality scores that are meant to represent an integrated method of the overall stress response of the fish that is manifest in ability perform 'normal' reflex actions, akin to a tertiary response. These reflex actions are necessary to complete normal body functions and movements, as such, they can be used to describe the automatic response of fish (or lack thereof) associated with capture stress, as well as be a proxy for a compromised physiological state (Raby et al. 2013). These impairments include venting, eye tracking, and re-establishing dorsal-ventral orientation after being inversed. RAMP scores were significant predictors of total mortality in Walleye pollock, rock sole (*Lepidopsetta bilineata*), sablefish (*Anoplopoma fimbria*), and Pacific halibut (Davis and Ottmar 2006). There have several recent studies on Pacific salmon that have used RAMP assessment to predict post-release mortality in coho salmon (Raby et al. 2012; 2014a) and sockeye salmon (Gale et al. 2011; 2014).

2.3.4 Infection

It is well established that stress from a variety of causes can suppress the immune system and promote infection and pathogen virulence (Fevolden et al. 1993; Schreck 1996; Crossin et al. 2008). Indeed, bacterial diseases of fish are almost exclusively stress related (Inglis et al. 1993). In cases where fisheries stress reduces a fish's ability to resist infection, microorganisms already present in a carrier state (causing no disease) may proliferate and cause disease (Inglis et al. 1993). Further, delayed mortality following injury is expected to be associated with enhanced vulnerability to pathogens resulting from exposure through wounds and impacts to immune function mediated by the physiological stress response (Baker & Schindler 2009; Lupes et al. 2006). However, literature relating capture events to disease development in a natural environment is limited due to the difficulties of following fish in the wild and collecting full profiles of pathogen data non-lethally.

As Pacific salmon are semelparous and have a fixed reproductive investment as they approach full maturation, energy expenditures will likely come at the expense of maintenance (Patterson et al. 2004). For example, the down regulation of immune genes occurs as salmon proceed through their freshwater migration (Dickhoff 1989), leading to high infection levels on spawning grounds (Miller et al. 2014). Further, disease state and immune function at time of arrival likely determine longevity on spawning grounds (Baker & Schindler 2009). If infection is elevated due to capture stress, mortality may occur prior to arrival on spawning grounds, where it is very unlikely to be detected (Patterson et al. 2007b), or longevity at spawning grounds decreased. It is thus important to consider the potential implications of additional stress and energy expenditure that occurs as a result of fisheries interactions in the context of susceptibility of Pacific salmon to disease.

The first line of defense to prevent infection is the mucus layer, followed by the epidermal layer. In the case of injury, these components are typically compromised and thus may ease entry of pathogens in to the target tissue. Consequently, any fisheries gear that disrupts the mucus and/or epidermal layers of non-retention individuals may increase the likelihood of infection. Research conducted by Svendsen and Bøgwald (1997) found that juvenile Atlantic salmon that were experimentally injured using a biopsy punch and exposed to pathogens had significantly lower survival compared to controls. Further, adult Pacific salmon subjected to experimental gill net treatments often had apparent fungal growth at the site of gill net marks (Art Bass, UBC, Vancouver, B.C., unpublished data). More research regarding the direct implications of fisheries related injury to pathogen infections is required.

Infective properties of pathogens may be directly influenced by water temperature through changes to host immune function and/or pathogen replication dynamics (Wedemeyer 1996; Marcogliese et al. 2001), causing increases in pathogen prevalence and loads. For example, some pathogens, such as the pathogenic ciliate *Ichthyopthurius multifiliis*, have accelerated life cycles in high water temperatures (Ewing et al. 1986). As with other physiological stressors, temperature stress reduces the condition of the host, and whether a pathogen becomes increasingly virulent in high water temperatures will depend on the susceptibility of both the pathogen and the host to high water temperatures (Miller et al. 2014). In a holding study using wild caught adult coho collected during spawning migration, fish held at high water temperature demonstrated decreased resilience to infections of pathogenic microbes compared to fish held in cold water (Miller et al. 2014). Further research is required to understand the interactions among stressors and how they influence the virulence of pathogens.

In summary, stress and energy expenditure associated with fisheries interaction may negatively influence the immune capacity of migrating Pacific salmon, while physical injury resultant from fisheries capture facilitates pathogen entry and/or proliferation (Baker & Schindler 2009; Lupes et al. 2006). These factors may increase the likelihood of pre-spawn mortality due to increased pathogen loads. Advancing technologies in biotelemetry and gene profiling are enabling researchers to address the influence of fish physiological condition, capture stress, and disease on the success of wild migrating salmon (Bass et al. in press). Teasing apart the major contributing factors to pre-spawn mortality is a challenge due to natural variability in physiological response and pathogen population dynamics.

2.4 GENERAL FISHING FACTORS

Our review of the literature and solicitation of advice from experts led to a long list of fishing factors that have been associated with FRIM. In general, these factors can be classified as general factors that are common to all or most fisheries, factors related to gear type, and finally factors related to variation in the method of fishing (i.e., within a gear type). Due to the lack of studies directly comparing different fishing methods, we have also included subsections with information relevant to the each of the dominant fishing types (i.e., major method/gear variants) used to catch Pacific salmon in British Columbia. We accept that fishing type is not a standard factor, but given that it typically includes unique gear/method variants we have included specific fishing types in this study as a potential factor. To connect each fishing factor to a mortality outcome we provide a mechanistic description of the link between the factor and mortality, if such information is available in the literature. Where possible we refer the reader to some of the review papers that focus on some of these factors. For each factor we have identified relevant considerations that are likely to influence the effect of the factor on mortality and the potential utility in evaluating its' contribution to FRIM. This includes a discussion of interactions with other factors, and the potential for a factor to be used as a surrogate for another factor (e.g., handling time and air exposure). In some cases we provide mortality rates from relevant studies to highlight the likely mechanism(s) associated with FRIM for the major types of fishing gears, and to compare among fishing gears. These examples are not meant as definitive mortality values for a given fishing method. The overall purpose of our review of each factor is to explore how each factor may be linked to mortality outcomes via the fish response pathways described in section 2.3.

Physical variations in fishing gear (within a generic gear type) that can affect catchability, or selectivity, are important because they can change the encounter to total catch ratio (i.e., percent of fish landed as a function of total encountered by the fishing gear). This ratio will influence the overall mortality rate if different mortality rates are applied to drop-off mortality and caught-release mortality. However, such information is beyond the scope of this paper. We focussed on gear variation that could affect the injury or stress response of the fish, not the catchability (e.g., twine colour, bait type). A similar issue is relevant for pre-capture behaviours that could affect the likelihood of fish being landed.

2.4.1 Capture Time

Capture time is the length of time elapsed from when a fish can potentially encounter gear in the water, either through direct contact or perception, to when the fish is brought to the boat or the shore (e.g., capture time ends were purse seine is alongside the boat). The duration of exposure a fish has to the total fishing encounter will tend to increase the probability of injury and the magnitude of the stress the fish experiences. The terms used in the literature to describe capture time vary widely and include, among others, soak time for gill nets, hook time, fight time, or play time for hook and line fisheries, tow time for trawling and set time for seine fisheries. The majority of evidence about the connection between capture time and injury or stress comes from the angling literature, with less information on trawling, gill nets, and seine netting (Broadhurst et al. 2006). The magnitude of the effect of capture time will depend on the type of physical contact, which is largely driven by gear type and can be modulated by other intrinsic and extrinsic factors (e.g., water temperature).

Hook time for angling, or trolling, is in reference to how long the fish is on the hook and line (also commonly referred to as a *fight time*). The longer fish stays on the line the greater the number of fight responses (Brownscombe et al. 2014a), which are characterized by burst swimming and the use of anaerobic white muscle, which typically leads to a build-up of lactate and the creation of an oxygen debt that must be repaid via excess post-exercise oxygen consumption. The increase in fight time will therefore increase the level of exhaustion experienced by the fish, increase the extent of the fish's departure from homeostasis, and increase the risk of depredation during the capture event, or of post-release predation. The former can result in extreme exercise stress and acute mortality, particularly if combined with high water temperatures or extended air exposure. The latter (depredation and post-release predation) can occur as function equilibrium loss, slower avoidance reactions upon perception of a predator, and/or reduced swimming ability. For example, the longer the period of time that bull trout were on the hook the greater the equilibrium loss (Gutowsky et al. 2011). For commercial troll fisheries, the presence of many simultaneously hooked fish (i.e., an elevated catch size) necessarily increase mean hook times due to limitations in handling a finite number at one time. The potential for exhaustion in troll fisheries can also be related to trolling speed and fish size, both of which would be expected to positively increase capture time by making it more difficult for the fisher to reel in the fish. Reviews on recreational fishing are consistent with respect to hook times being directly related to the magnitude of the fish's response (Cooke et al. 2013), and to mortality (Bartholomew and Bohnsack 2005).

Soak time is generally a term used for set nets (gill nets) that "soak" for a period of time. Increased soak time for gill nets will generally attract predators, increase the number of escapees, and increase the number of drop-outs. An increased soak time can also deter other fish from potentially entering the net, as fish that are already entangled become both a visual cue for avoidance, and will change the shape of the adjacent net openings (pulling them in such a way as to make them more difficult to become entangled in). In general, longer soak times are reflected in greater physiological disturbance (Farrell et al. 2000) and higher mortality (Buchanan et al. 2002).

Set time is the common term for seine fishing and is akin to tow time for trawling. Both terms are defined as how long a net is out drifting or being towed before being pulled on deck, pursed abreast of the boat, or bagged tight near the shore. Longer set times lead to greater levels of physiological stress, confinement stress, exhaustion, injury, and anoxia (Marçalo et al. 2006). The latter is more relevant to cod-ends for trawling and very large catch sizes for seines (Broadhurst et al. 2006).

Trap time is the length of time fish are within trap box or trap net prior to handling. Longer trap times cause greater confinement stress and potential for injury for those fish trying to escape (Colotelo et al. 2013).

A fish's response to capture time (i.e., the relative effect of each added minute to capture time) is not equal across fishing gears. Thirty minutes on a hook or enveloped within a gill net will elicit a greater negative response from the fish than 30 minutes encircled in a purse seine or holding within a trap. The reason for this disparity is that intense burst swimming activity is typically elicited more frequently in some fishing encounters than in others. Fish captured in trap or seine net can simply rely on sustained swimming ability to maintain position in response to variations in water currents. Fish that are hooked or physically entangled will typically use more burst-type swimming in attempts to escape and exercise fully to exhaustion or until they are freed. Even fish that use prolonged swimming to maintain position in a set net will eventually exhaust both aerobic and anaerobic capacity. Intense burst swimming or prolonged swimming to exhaustion will result in a build-up of waste products that can be detrimental to recovery and survival (Wood et al. 1983; Ferguson and Tufts 1992; Farrell et al. 2001a). The ability to recover from either prolonged or burst swimming will influence predation rates of escapee and released fish.

2.4.2 Handling Time

Handling time here is defined as the period of time from when a fish is landed to when it is released, with landed being defined as the moment when the fish is under full control of the fisher. Handling time can include the total time fish are handling in air and in water. For example, in a purse seine fishery, handling time would include the period during which a seined fish is inside the bagged seine, crowded with other fish adjacent the boat, before being sorted, removed and released. In a recreational fishery, the moment of landing would be defined as when the fish has been brought into shore, onto the boat, or into a landing net. The acute effects of handling are related to the injuries associated with hook removal, for commercial net boats those inflected during on-deck sorting, and in general related to the stressful effects of confinement. The delayed effects of handling result from the immune suppression and lowered disease resistance that can persist for days after handling (Maule et al. 1989; Burnley et al. 2012).

Handling times can vary substantially both within and across fisheries based on a number of factors. Similar to capture time, the longer a fish is being handled the greater the risk of injury and higher the stress response (Davis 2002). For all net/trap fisheries, the handling times associated with sorting are primarily influenced by catch size and species composition, most notably the proportion of the catch that must be released. Sea state, the type of sorting gear used, handling techniques, and the use of revival devices can all affect handling times. In commercial troll fisheries, the handling times are most influenced by the use of a revival box treatment, handler experience/technique, and the number of fish simultaneously hooked. For rod and reel fisheries, the terminal tackle and gear removal tools used can influence the time necessary to de-hook a fish, as can the experience and ability of the fisher. Other instances where total handling time could be increased in recreational fisheries are when the fisher is fishing alone, if photos are taken, if revival practices are used (e.g., manual revival techniques), and if the fish is particularly large, making landing and handling more difficult. Because handling time and its effects on the fish's stress response and injury are variable within and among fisheries, we discuss below some important aspects of handling time that can have major influences (general, across fisheries): variation in handling techniques, air exposure, and the use of revival techniques

2.4.3 Handling Technique

The methods used to handle fish once they are landed, brought to shore or the boat, vary substantially among different fishing gear types but also among fishers or fishing crews within a given fishery. The extent of a fisher's experience in both fishing and fish handling can often have a large effect on the duration and severity of handling, particularly in recreational fisheries, where there is substantial evidence to support the notion that fisher experience effects the magnitude of the fish's response and the likelihood of mortality. In commercial fishing of any sort there will be variation in handling techniques (e.g., among fishing crews), but presumably less variance in experience among handlers. Time required to sort a catch decreases with experience due to learned abilities to rapidly identify and handle non-target species in commercial fisheries, but the impact of these differences in experience is likely to have a minimal effect when compared to in recreational fisheries. However, we are unaware of any direct surveys of fisher experience in commercial fishers and its effects of the response or survival of the fish.

Experienced fish handlers may in many cases know how to hold a live fish in such a way that reduces stress and injury (in all fisheries) and will likely be more adept at hook removal, for instance. Cooke et al. (2013) discuss angler experience in their review, noting that both the behaviour and skill level will greatly influence landing and de-hooking times (summarized in Cooke et al. 2013; Diodati and Richards 1996; Dunmall et al. 2001; Meka 2004). Since the level of experience can lead to longer capture times and handling times, handler inexperience can lead to amplified physiological stress. For example, the lactate levels in largemouth bass angled for five minutes were much higher than in bass angled for one minute (Gustaveson et al. 1991).

In an extensive review by Arlinghaus et al. (2007), they reported that angler experience (or ability) can affect how the fish are hooked, and that mortality was lower for fish that were caught by experienced anglers than by those that were caught by novices (Arlinghaus et al. 2007; Diodati and Richards 1996; Meka 2004). This factor is likely important for evaluating the generalizability of mortality estimate studies that only used experience anglers.

There is a large degree of variability in fishers' attitudes and approaches to fish and their well-being. In commercial fisheries perception of conservation concern for the non-target catch and mistrust of regulatory bodies have been identified as causes of non-compliance with suggested best bycatch handling practices (Campbell and Cornwall 2008). People also hold diverse beliefs regarding the ability of fish to feel pain, variation in these beliefs could potentially affect handling practices. Several reviews address the issue of sentience, pain experience, and animal welfare in the context of catch-and-release fishing (see Arlinghaus et al. 2007, Cooke and Sneddon 2007, Davie and Kopf 2006; see Diggles et al. 2011 for commercial fishing).

In recreational angling there are tools that can be used to make fish handling more efficient, such as landing nets, pliers to remove hooks, specialized easy-release hooks, and gloves. The use of handling gear can potentially influence fish injury. As an example, gloves can improve grip on the fish, allowing gentler handling and possibly lower handling times, yet they can also disturb the important mucus layer on the skin surface which can expose the fish to post-release infection (Fast et al. 2002), which can be especially problematic when fish are in warm freshwater.

In commercial fishing operations, there are both standardized pieces of sorting gear and boat specific methods that have developed to optimize fish handling. These variations can influence handling time and injury potential (Broadhurst et al. 2006). Purse seine vessels likely have some of the most variable fish processing gear. For example, there is a big difference in handling impacts between brailing vs. ramping (bringing the fish up a ramp on the stern) to bring fish aboard. The latter has been shown to cause greater physiological disturbance (Farrell et al. 2000) than brailing, which involves using a large hydraulically-assisted dip net (the brailer) to sequentially bring subsets of the catch on board from the pursed seine adjacent the boat. Ramping is now uncommon in most areas of British Columbia, but there exists substantial differences in brailer size among boats and how tightly the seine is pursed during brailing. If fish are crowded in the pursed seine during sorting, resultant injuries are greater than if the net is left relatively loose during brailing, regardless of set size (K. Cook, UBC, Vancouver, B.C., unpublished data). Once on board, the use of specialized water-filled sorting trays, overboard chutes to release fish, and/or revival boxes can each reduce injury and improve fish release condition by minimizing air exposure (Farrell et al. 2001a,b). Commercial trolling and gill net vessels can also use revival boxes, as well as different handling tools for removing fish from gear (e.g., gaffs). Each of these variations in handling techniques and tools have potential to modify injury or stress experienced by the fish.

2.4.4 Air Exposure

Air exposure is a critical subset of overall handling time because it can directly cause immediately mortality or lead to substantial physiological stress from which fish may have difficulty recovering (Davis 2002; Cook et al. 2015). Air exposure is a part of the handling experience, but is considered separately from handling time here due to its relative importance in the response of fish and their subsequent survival. Exposing a fish to air impedes oxygen uptake, and therefore represents an acute anoxia for fish (i.e., asphyxiation). When in air, gill filaments adhere to one another, and the gill lamellae, the respiratory organs responsible for gas exchange, collapse (Ferguson and Tufts 1992). Gas exchange occurring via capillaries in the gill lamella stops, ceasing aerobic respiration (Ferguson and Tufts 1992). An oxygen debt develops and carbon dioxide accumulates, decreasing blood pH (i.e., extracellular acidosis; Ferguson and Tufts 1992; Suski et al. 2004). As an acute stressor, asphyxia activates the hypothalamic-pituitary-interrenal (HPI) axis and triggers a physiological stress response, increasing lactate, glucose, and cortisol concentrations (Arends et al. 1999). The longer the duration of air exposure, the greater the physiological stress response and the longer these effects take to recover (Chopin et al. 1996). This common response has been repeated for other studies looking a variety of fish species (e.g., Cooke et al. 2001, 2002 and Killen et al. 2006). A recent review by Cook et al. (2015) provides a good summary of the mechanisms associated with air exposure in the context of fishing.

Air exposure is likely unavoidable for virtually all fish captured and released given the need to extract fish from the capture gear. In commercial fisheries, air exposure can be particularly prolonged during on-board sorting. Given the necessity of efficiency in commercial operations, the release of bycatch is sometimes not prioritized, leading to extensive air exposure. Air exposure for recreational fishing is most often associated with hook removal and photographs. However, specific air exposure threshold recommendations for commercial bycatch species or recreational fisheries are rare (Cook et al. 2015). There is no universal lethal threshold for air exposure duration; variables such as environmental conditions, species, or life history stage can all factor into tolerance. There is minimal research available on critical thresholds of air exposure for Pacific salmon, especially during the marine phase of the spawning migration, or on differences in vulnerability among salmonids species or populations.

The air exposure durations that fish can survive vary dramatically among fishes, presumably because of natural taxonomic differences in lifestyle and hypoxia tolerance, and therefore some species are less instructive for understanding air exposure thresholds in Pacific salmon than are others. Unlike Pacific salmon, some common bycatch species in Pacific trawl fisheries, most notably demersal fishes, can survive protracted (> 20 min) air exposure during sorting. For example: Pacific halibut had no mortality during 10 days following simulated trawl capture and 30 minutes of air exposure (Haukenes and Buck 2006; similar thresholds identified by Davis and Schreck (2005) and Oddsson et al. (1994)); Lingcod (*Ophiodon elongatus*) had no immediate mortality after 45 minutes air exposure in adults (Davis and Olla 2002); and Sablefish survived after 30-45 minutes of air exposure following simulated commercial capture (Davis and Parker 2004) but indications of immunosuppression resulted after 15 minutes of air exposure (Lupes et al. 2006). The overall resilience of salmon to air exposure is varied but generally much less than the numbers cited above for demersal fishes because of their relatively active lifestyle, higher requirements for oxygen, and much lower tolerance to hypoxia. Ferguson and Tufts (1992) working on cannulated rainbow trout (*O. mykiss*) found increased mortality after only a minute of air exposure and Schreer et al. (2005) reported drastic impairment in swimming in Brook trout (*Salvelinus fontinalis*) after a 2 min air exposure. In contrast, spawning pink salmon (*O. gorbuscha*) salmon survived 8 minutes of air exposure in cold waters at spawning areas (12°C; Raby et al. 2013). Severe impairment (i.e., equilibrium loss) increased with air exposure duration, but mortality did not begin to occur until air exposure reached 16 min (Raby et al. 2013). The lack of mortality associated with such prolonged air exposure was likely related to the advanced maturity of the salmon and the cold water (and the lack of predation). Similarly, Donaldson et al. (2011) found the less mature population had higher post-release mortality after a similar capture stress and air exposure treatment of 1 min. In unpublished research on chum salmon (*O. keta*) assessing reflex impairment following experimental air exposure and consistent capture conditions by purse seine, data suggests that high mortality is likely between 3 and 5 minutes of air exposure. However, high impairment scores were also observed after 1 min of air exposure (K. Cook, UBC, Vancouver, B.C., unpublished data), and in angled-and-release sockeye salmon in the lower Fraser River, just 1 min of added air exposure was enough to decrease survival (Donaldson et al. 2013).

High mortality following air exposure can also be strongly affected by water temperature and, in some cases, by the age/size of the fish. For example, Little Skates (*Leucoraja erinacea*) exposed to 50 minutes of air exposure in both the winter and summer suffered mortality rates of 27% and 100%, respectively (Cicia et al. 2012). For lingcod bycatch, Davis and Olla (2002) recommended that at temperatures greater than 16 °C and with air exposure for greater than 30 minutes, mortality is sufficiently high that releasing smaller fish is not an effective management strategy. Younger and smaller fish are generally more sensitive to capture stress, and exhibit greater behavioural impairment and mortality as a result of air exposure (Davis 2002). Additionally, an inverse relationship between core body temperature and fish size suggests that elevated air temperatures are more detrimental for small fish (Haukenes and Buck 2006). There are several examples from the literature. Air exposure thresholds identified to be 60 minutes for age-2 lingcod but 40 minutes for age-1 lingcod (Davis and Schreck 2005) and 100% mortality resulted after 60 minutes of air exposure in small Lingcod but not until 75 minutes for larger Lingcod (Davis and Olla 2002). Similar results have been found for sablefish (Davis and Parker 2004; Davis 2005) and younger Pacific Halibut showed greater physiological disturbance as a result of air exposure (Davis and Schreck 2005). However, there is a challenge in applying this research to salmon, as an opposite trend in coho salmon has been reported; larger fish had longer recoveries following exhaustion and air exposure (Clark et al. 2012). It should also be noted that high air temperatures could increase the chances of dehydration and damage of gill lamellae when air exposure is prolonged, reducing the capacity of the fish to recover after it is returned to the water, such that a 2 min air exposure with air temperatures of 30°C would likely have more serious consequences than the same duration of exposure on a 15°C day. However, there are few data available to assess the modulating effect of air temperature on the impact of air exposure in Pacific salmon, perhaps partly because it is difficult to experimentally control air temperatures in experiments using adult salmon.

The relevance of air exposure for FRIM in Pacific salmon is partially limited by the lack of research directly aimed at identifying air exposure thresholds that cause post-release mortality. However, it is clear from the literature that air exposure duration is positively correlated with mortality; in no study does air exposure improve survival of released fish. And in salmonids, even small amounts of air exposure (e.g., 1 min) have been shown to increase mortality in some cases. Given a known effect of air exposure on mortality, reducing air exposure duration in Pacific salmon fisheries is likely to increase survival in almost all contexts. Van Beek et al (1990) describes faster processing of sole and plaice bycatch and greater survival with the use of a conveyor belt with a continuous water supply. Similar operations could be implemented in some selective Pacific salmon fisheries to reduce the effect of air exposure.

2.4.5 Revival Technique

Revival methods and techniques include any kind of attempt to allow for recovery, revival, or rest prior to release. Attempts at revival, either through manually holding a fish in the river current (e.g., in a river fishery) or through leaving fish in flow-through revival containers (among other methods), is a component of overall handling time. The most common methods include holding containers (boxes, tanks, or bags) in which the fish that appear to be moribund or behaviourally impaired are placed temporarily until they regain indicators of vitality (such as positive equilibrium). An effective strategy for salmonids in experimental studies has been the use of low-velocity swimming, as opposed to recovery in static (non-flowing) water (see Milligan et al. 2000; Farrell et al. 2001a). Other methods include manual ventilation assistance (see Robinson et al. 2013, 2015), a common method employed by anglers, and controlling the conditions of a static holding/recovery environment (i.e., temperature controlled or salt-added water in a live well). The mechanism behind the benefit of revival methods is well established. Severe exercise associated with capture results in a built-up of metabolic by-products associated with increase anaerobic activity. Oxygen is required for the re-synthesis of glycogen stores and to cope with by-products. Revival approaches aim to direct additional water flow across the gills to assist ventilation and increase oxygen transfer. Revival techniques are likely to be particularly effective if a fish has lost the ability to ventilation properly on its own (i.e., vigorous opening and closing of the opercula), or if it were to drift downstream upon release, precluding ram ventilation of the gills.

Survival benefits of revival methods for Pacific salmon have been demonstrated in empirical studies in the marine environment, results that have led to the possession and use of revival equipment to be a condition of licence for some commercial salmon fisheries. This requirement stemmed from early work focussed on revival tools for coho salmon in British Columbia, Canada, in association with selective fisheries in marine waters (e.g., Blewett and Taylor 1999; Farrell et al. 2000, 2001a, 2001b; Buchanan et al. 2002). This research clearly demonstrated that fish could, in the short term, regain equilibrium following capture events through the use of revival gear. More recent work has focussed on in-river fisheries under warmer temperatures using modified revival methods and a broader range of salmon species. The beneficial effects of revival varied across studies. There was no survival benefit of manual ventilation techniques being applied in either field or lab studies for sockeye salmon after being exposed to combinations of handling stress, exhaustive exercise, and air exposure (Robinson et al. 2013, 2015). For streamside bags and ventilation boxes that are similar to the marine revival boxes, the results were mixed, but these devices were reliably able to revive sockeye salmon in freshwater that appeared moribund after seine capture and a 3 min air exposure (Raby et al. 2015d). Fish that were severely impaired did have beneficial improvement to reflex responses from the revival treatment and some modest long term survival benefits (Nguyen et al. 2014). However, fish that were able to regain equilibrium and show signs of vigour prior to revival treatment did not benefit from the treatments (Nguyen et al. 2014). Donaldson et al. (2013) did show positive physiological benefits of revival techniques on pink salmon and sockeye salmon, but failed to find a strong statistical link between revival method and survival to spawning areas. The collective results from both the marine and freshwater work suggest that benefits of reviving severely impaired fish needs to be tempered with the added stress of holding or confining a vigorous fish (Raby et al. 2015d) – i.e., fish should always be released when vigorous or if they can maintain positive equilibrium (Farrell et al. 2001b). And indeed, in some of the studies described above, many fish being exposed to revival techniques were able to maintain positive equilibrium without assistance. In addition, there are practical limitations to the application of revival methods in scenarios with high catches of non-retention species, whereby revival gear use would have to be carefully prioritized for the most impaired fishes.

2.5 NET AND TRAP FISHING

2.5.1 Catch Size

Catch size, also sometimes referred to as catch density, refers to how many fish are caught per net set. Large catches increase sorting and processing time, so handling time and the potential for injury and stress increase. Not only can large catch sizes lead to lengthy handling times, but they typically lead to higher crowding densities. Highly crowded or dense catches can lead to hypoxic conditions (Raby et al. 2014a), squishing or crushing injuries.

There is a small amount of documented evidence related to catch size, even though it is assumed to play a role in the magnitude of the fish's physiological disturbance, the likelihood of injury, and subsequent mortality. In their extensive review of mortality from towed fishing gears, Broadhurst et al. (2006) propose that more attention needs to be paid to catch size and composition in future studies, and mentions that most studies dealt with only small catch sizes. In Pacific salmon seine and gill net fisheries, larger catch sizes would typically be associated longer capture and handling times. Indeed, in a study that took place with a purse seine vessel, larger catch sizes tended to decrease the vitality of bycatch even within the relatively small range of catch sizes in that study (Raby et al. 2015c). However, direct relationships between catch size and mortality in Pacific salmon remain largely anecdotal. Many fishers and researchers alike have reported observations of deteriorating condition, increased impairment, and more severe injuries in non-target fish with large catch sizes. There are few data to support this notion except one study identifying time in net, a surrogate measure for catch size, as the best predictor of 24 hour mortality in 47 adult Chinook salmon released from purse seines (Candy et al. 1996). In a simulated purse seine fishery for pink salmon where mortality of 220 coho salmon caught as bycatch was quantified, 14 sets were conducted that ranged from approximately 100 to 3500 fish but set size was not a significant predictor of post-release mortality as quantified by acoustic telemetry, although injury or reflex impairment did predict short-term (48-96 h) post-release mortality (K. Cook, UBC, Vancouver, B.C., unpublished data). More research is required either aboard active vessels in-season or with simulated fisheries that accurately represent in-season fishery conditions.

2.5.2 Crowding

Crowding refers the practice of corralling fish into a tighter space, forcing fish into direct contact with fishing gear or other fish, to enable efficient processing of the catch. For purse seines this involves tightened the bag after the purse has been sealed to facilitate brailing or ramping. In beach seines the net is bagged tighter after the lead line has been brought ashore to facilitate sorting on the shoreline. Crowding is also possible in trap nets, if the traps are overloaded forcing repeated physical contact among fish, and/or the trap. Crowding has been noted as a potential serious issue for estimating fishing impacts (Davis 2002; Broadhurst et al. 2006). A main consideration is the length of time fish spend in direct contact with each other and with the net, leading to increased risk of asphyxiation, injury, and general stress (Davis 2002; Marçalo et al. 2006; Donaldson et al. 2010; Raby et al. 2015b).

The limited work done on the effects of crowding has focussed on small pelagic marine fish. Experiments on crowding mackerel (*Scomber Scombrus*) indicate clearly that the density of fish within the net is direct determinant of cumulative mortality (Lockwood et al. 1983). Similar work on schooling herring also found a marked threshold response to increasing seine net density and mortality (Tenningen et al. 2012). However, work on sardines (*Sardina pilchardus*) was found to be inconclusive with respect to density effects (Marçalo et al. 2010) but crowding time itself was a significant predictor of mortality (It should be noted that Marçalo et al. (2010) called crowding 'confinement', one example of the inconsistency in terminology that can cause problems in literary reviews of FRIM). In one of the few direct studies on Pacific salmon, Raby et al. (2015a), simulated beach seine crowding and held coho salmon in a tight net for 2 and 15 min periods under and 10°C and 15 °C scenarios. Mortality only occurred at 15min and high temperature condition. This also highlights the key consideration of water quality, such as water temperature and dissolved oxygen, in crowding studies. The role of dissolved oxygen is more complex, given that fish in a well oxygenated environment are better capable of repeat burst activity, increasing the probability of injury and exhaustion. However, as dissolved oxygen declines fish can become more acquiescent up until another lower dissolved oxygen threshold level and they begin to panic again (see dissolved oxygen section 2.8.2). Crowding can increase the potential for horizontal transmission of pathogens and lead to increase potential of injury depending on catch composition (See catch composition 2.5.4).

2.5.3 Confinement

Most wild fish do not respond well to confinement (i.e., enclosed space without crowding), such that they mount a stress response (Wedeymeyer 1996; Barton 2002; Portz et al. 2006). Very few studies directly address confinement stress, and for those that have done so, it can be difficult to tease apart what stress is owed to confinement alone. A study on sockeye salmon by Donaldson et al. (2011) demonstrated that the added confinement stress of holding fish for 24hrs resulted in major physiological stress response. More importantly, radio-tagged fish held for 24hrs in confinement (large nets with low density) had significantly higher mortality than fish released immediately. The same pattern occurred in marine-caught coho salmon whereby the time-specific rate of mortality was higher in fish held in a net pen than in those telemetry-tagged and released, with physiological data confirming that delayed stress caused by confinement was likely contributing to mortality (Raby et al. 2015c). Even differences in short-term confinement can affect the physiological disturbance that fish experience; Donaldson et al. (2010) found that fish corralled in a confined space for 30 minutes exhibited elevated heart rate for an average of 11.5 h whereas fish corralled for only 10 min returned to resting heart rate after an average of 7.6 h. Confinement stress is an important consideration when evaluating the quality of holding studies. The principal difference between confinement stress and the stress associated with being either constrained (e.g., in a net or by a handler) or crowded (i.e., direct physical contact with other fish or gear) is that the latter is more likely to lead to exhaustive stress and injury, whereas confinement stress involves a sustained neuroendocrine response that can interfere with physiological recovery and injury repair.

2.5.4 Catch Composition

The catch composition, the size and species variation within a catch, can influence stress and injury response of fish. There is little direct evidence of effects of catch composition with salmonids; however, some studies do discuss certain unfavourable catch conditions. For example, abrasive bycatch (e.g., fish with spines, crustaceans) are assumed to increase injury (reviewed in Broadhurst et al. 2008). Broadhurst et al. 2008 was one of a few studies that cited the presence of jellies as bycatch to be a significant predictor of mortality. Presence of jellyfish is especially a concern to Pacific salmon in purse seine fisheries where they are commonly crowded among captured salmon. Although the effects of this remain untested, an experimental challenge study revealed that jellyfish cause severe gill damage in marine-farmed Atlantic salmon smolts; damage that can persist for up to three weeks (Baxter et al. 2011). Further research has investigated the pathology associated with jellyfish encounters in salmonids (Mitchell et al. 2013; Marcos-López et al. 2016). Catch composition, as with "catch size," was identified by Broadhurst et al. (2008) as an area that deserves more attention when assessing FRIM mortality.

2.5.5 Mesh Size

The size, shape, and material of the mesh used in any net or trap can have a major influence on the type and extent of injury and stress an exposed fish will experience. The ability of an animal to escape a net depends in part on its transverse morphology in relation to available openings, and so the size and shape of meshes will influence physical damage and mortality (Broadhurst et al. 2006). However, the effects of mesh size are inconsistent with trawl gear, with some studies indicating the potential for some correlation with mortality across similar sizes of fish, while others have clearly demonstrated no relationship (Main and Sangster 1988; Suuronen et al. 1996). The influence of mesh configuration or shape also remains unclear. Main and Sangster (1988) observed that proportionally more haddock (*Melanogrammus aeglefinus*) died after escaping through square-shaped mesh than through diamond-shaped meshes in the North Sea, but DeAlteris and Reifsteck (1993) did not detect similar effects for scup (*Stenotomus chrysops*), winter flounder (*Pseudopleuronectes americanus*), or Atlantic cod (*Gadus morhua*) off Northeastern United States.

A key consideration for Pacific salmon is fish size, which will dictate the severity of the interaction with a net. For example, if a non-target species in a purse seine fishery is smaller than the target species, it may be prone to becoming gilled in the seine mesh. Conversely, in gill net fisheries, those fish larger than target fish will only become entangled as would occur in tangle net fisheries rather than being gilled, whereas fish smaller than the target species will be able to slip through the mesh, potentially escaping major injury and handling. The implications of being gilled are greater than entanglement or corralling in a pursed net, as described in 2.3.2. Vander Haegen et al. (2004) observed substantially reduced mortality in spring Chinook salmon released from tangle nets compared to gill nets but little difference between 8 and 5.5 inch gill net, likely because they both caused gilling in the study species. In pink salmon purse seine fisheries, there is concern that coho encountered as bycatch can become gilled. Therefore Raby et al. (2015c) conducted three experimental sets in on a purse seine vessel where the netting was changed from the industry standard of 100-mm bunt to 70-mm knotless nylon mesh. The result was improved condition and reduced impairment in adult coho and no immediate mortality, but high bycatch of juvenile salmon for which scale loss was very high (Raby et al. 2015c).

2.5.6 Mesh Type

Prior work on mesh type has focussed on catchability and selectivity (e.g., mono vs. multifilament) and not necessarily on the animal-level response to the gear. Hunter et al. (1970) reports higher mortality from multifilament compared to monofilament gill nets in sockeye salmon. Some work on mesh material with respect to injury or capture stress has focussed on the potential benefits of knotless nets, with knots often being a cause of particularly severe injuries. For example, Barthel et al. (2003), compared different landing nets with different mesh types and confirmed that coarse and fine knotted nets resulted in higher injury scores and mortality than did smooth knotless nets. However, the magnitude of this effect is likely small based on low mortality rates of 4 to 14% among net types in that study (Barthel et al. 2003). We are not aware of any studies that have rigorously assessed the effect of knotted versus knotless nets in Pacific salmon.

2.5.7 Major Net Fishing for Pacific Salmon

There are several major differences in the net fishing methods and gear variants used to target Pacific salmon. The type of net used and how the net is deployed is controlled in large part due to the environment (i.e., marine, fresh water, velocity), but both the gear and method will influence the stress and injury response. Here we outline some of the important net fishing techniques used by salmon fishers in the Pacific region of Canada.

2.5.7.1 Gill net drift

Gill net drift fishing is part of the prolific small-scale gill net fisheries that encompass drift, set and tangle nets, all of which are used to target Pacific salmon. Drift net fishing is distinguished from set gill nets in that the gill net is allowed to drift for several minutes or hours, either downstream in the river current, or in ocean currents, before it is pulled aboard for processing. These nets are also different than tangle nets in that the mesh size is designed to cause fish to be gilled, i.e., ensnared by the net posterior to the opercula and anterior to the dorsal fin (mid-point of the body). Conversely, tangle nets used smaller mesh sizes so that fish are entangled around their nose, jaw, and/or teeth, preventing fish from being asphyxiated and typically reducing the extent of scale loss.

The constrictions resulting from net encirclement around the body and gilling are known to cause substantial injury, which Kojima et al. (2004) revealed can lead to fatal physiological conditions. Indeed, research by Baker and Schindler (2009) confirmed that sockeye arriving at spawning grounds with gill net injuries have reduced longevity and reproductive success. Therefore unsurprisingly, mortality and/or impairment is consistently greater in fish released from gill nets than from other capture methods (e.g., seining [Broadhurst et al. 2008], tangle net and beach seine [Donaldson et al. 2012], tangle net [Vander Haegen et al. 2004], hook and line [Murphy et al. 1995]). The few mortality estimates provided in primary literature of gill net captured fish are highly variable, emphasizing the importance of methodological differences (e.g., soak times) and difficulties with applying a single mortality estimate to a gear type without considering other factors. For example, Donaldson et al. (2012) observed 100% mortality to spawning in sockeye salmon from the Harrison River population exposed to a mild gill net capture simulation. Vander Haegen et al. (2004) calculated post-release mortality to be 49% for an 8" gill net and 43% for a 5.5" gill net in Chinook salmon, but with short soak times, careful handling, and use of a Fraser box for revival. Buchanan et al. (2002) found that short-term mortality of coho salmon released from gill nets can be as low as 6%, but we caution that much of the mortality caused by gill nets is likely to be delayed (days after release) because of pathogenesis associated with the injuries incurred (e.g., skin, scale, and mucus loss).

2.5.7.2 Gill net set

Gill net set fishing refers to hanging a gill net in a set position through the use of anchors. This is a common method of deployment in high velocity turbulent water areas (e.g., Lower Fraser canyon) where fish are forced to migrate close to shore. Setting a net in place means it can be left for hours (e.g., overnight); potentially accumulating dead catch, increasing the number of drop-outs, and increasing capture time for fish that do survive. Depending on water clarity set-nets can be used effectively both during the day and at night. The injury response to a gill net set fishing would be similar to gill net drift fishing. A potential difference in the physiological response would be the need for swim harder once entangled to maintain position, unlike an in-river or ocean drift net where they are typically moving with the current. The added cost of prolonged swimming could make fish caught in set nets more vulnerable to longer soak times. For gill nets that are not actively checked, the potential for drop-outs would increase with soak time. Fish that drop out would sink and it is unlikely they would re-surface (Patterson et al. 2007b).

2.5.7.3 Tangle net

Tangle nets are essentially identical to gill nets except that the mesh size is much smaller (or the hang ratio is adjusted to minimize snaring) than that which would be required to gill fish; instead the net is designed to tangle around the jaw/teeth/fins of the fish. As such the risk of injuries are less, but there is a still a risk of suffocation associated with the operculum being covered if they are not checked frequently. Overall, the probability of successful resuscitation and release following capture by tangle net is more likely than with gill net capture (Donaldson et al. 2012; Vander Haegen et al. 2004). The best estimate of mortality for tangle nets is provided by Ashbrook et al. (2008) who used a modeling approach with large samples sizes and natural mortality incurred from a control trap caught group to conclude mortality for Chinook salmon released from tangle nets to be 18.31-44.54%. Authors caution results were obtained with short soak times and careful fish handling and may differ from actual fisheries.

2.5.7.4 Purse seine

A seine net hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats. Seine nets encircle groups of fish and can be deployed from the shore as a beach set, or from a boat as an open set. Seining is traditionally done in areas with large schools or groups of fish and consequently, purse seining catches the largest biomass of Pacific salmon in BC. Few primary publications have directly investigated mortality in fish released from purse seines but those existing data provide results that are generally more consistent than observed for other gear types. Candy et al. (1996) used acoustic telemetry to estimate 24 hr mortality of Chinook salmon to be 23%, very similar to the 21% 24 hr mortality estimate for coho salmon resulting from holding studies conducted by Raby et al. (2015c). In terms of delayed post-release mortality, Raby et al. (2015c) estimated 20% mortality from coho released from purses seines during the first 48-96 hr and 47% mortality to river entry (i.e., release in Area 20 to detection in or near freshwater entry). This preliminary study had small set sizes and small sample sizes. The following year is was repeated to mimic more realistic fishing conditions (i.e., larger sets), resulting in estimates of post-release mortality ranging from 18 to 47% during the first 48-96 hr and 58 to 86% to the Fraser River estuary that were influenced by population of origin (K. Cook, UBC, Vancouver, B.C., unpublished data). Such mortality studies using telemetry have not been conducted in other areas or for other species released from purse seines. The primary aspects of purse seines likely to modulate the extent of physiological disturbance are: the catch size (and sorting time), the density with which fish are crowded during sorting, and whether fish are brailed or ramped. Injuries in purse seine fisheries will primarily be determined by the type and size of mesh used in the seine net and in the brailer (Raby et al. 2015c).

2.5.7.5 Beach seine

Beach seines for salmon normally involve the deployment of a large nets pulled with the current via a boat to encircle upstream or holding fish in riverine environment. As in purse seine fisheries, mesh size is an important determinant of injury. Selection of mesh size is trade-off between not gilling the target species (and other potential bycatch) and minimizing drag. The capture time is a function of net length and the methods for bringing to methods (e.g., mechanical assistance vs. manual hauling). Further considerations for understanding FRIM associated with beach seining are the quality and quantity of water (Raby et al. 2014a). High water and high velocities may necessitate fish being crowded in shallower areas for safety reasons. This is similar to ramping in rough seas and can increase crowding densities and air exposure, but reduce crowding time and potentially sorting time.

Estimates of mortality to spawning in Pacific salmon (coho and sockeye) released from beach seines are similar to those observed by purse seines in the marine environment. Experimental studies have produced mortality estimates from release to spawning ranging from 23% to 67%. Although scale loss and bruising can occur during seine capture, mortality is often less for fish released from beach seines when directly compared to other methods (e.g., Donaldson et al. (2011) observed 52 and 36% mortality to spawning in sockeye for beach seining and angling, respectively and Donaldson et al. (2012) observed 67% mortality to spawning in Harrison sockeye salmon released from beach seine but 100% and 91% for those released from gill and tangle nets, respectively). Comparatively lower mortality was observed in coho salmon released from beach seines (3% immediate mortality, 19% by 48 hr, and 39% to spawning; Raby et al. 2014a).

All mortality estimates using telemetry include natural mortality as well as any tag-induced mortality. However a few studies have attempted to understand mortality attributed to beach seine capture alone while controlling for natural mortality. Using model data from Martins et al. (2011) suggests 70% survival from first detection in lower Fraser River to spawning for sockeye salmon, the reduced survival relative to a natural mortality baseline for sockeye captured and released from beach seines was estimated to be 12.5% (Donaldson et al. 2013). Raby et al. (2014a) took a different approach, using a relationship between vitality and post-release mortality to estimate natural mortality, and provided what they considered to be a conservative estimate of coho salmon dying as result of beach seine capture of 16.6% (95% CI of 13–21%); a rate of mortality that is meant to empirically exclude that caused by natural or tag-induced mortality.

2.5.8 Other Net/Trap Fisheries

There is very little information in the primary literature on the responses of fish to less common fishing gears used to capture Pacific salmon, such as dip nets, reef nets, weirs, and fishwheels.

Dip net – Capture of Pacific salmon by dip net is a traditional method that likely results in minimal trauma to the released fish given rapid capture and handling times. There is no known study on the effects of dip nets, but impacts to released fish would be dependent on the mesh type and size of the dip net as is the case with landing nets used in recreational fisheries (see section 2.6.2).

Reef net – Reef netting is a historical fishing method by which a nylon net is suspended between two boats near the river's mouth during a flood tide. Spotters wait for a school of salmon to swim over the net and it is then quickly pulled up using winches. We found no studies on the effects of reef nets to fish survival. The effects on released fish would likely be similar to tangle nets but without the prolonged gear encounter time.

Weir – A fishing weir is an obstruction across a river that can be used to trap Pacific salmon as they migrate upstream. There is no known study on the effects of weir capture to Pacific salmon. The main aspect of this capture technique that would affect a deleterious response in the fish would be the stress of confinement and crowding associated with prolonged holding in the trap (see sections 2.5.1 and 2.5.3 on crowding and confinement), effects that would be reduced in traps that are tended frequently.

Fishwheel - A fishwheel operates as a water-powered mill wheel. As the wheel rotates with the current, baskets scoop up fish travelling upstream, against the direction of the current and the movement of the fish wheel. Near the apex of rotation, fish descend from the baskets into holding tanks. There have been a few studies using fishwheels to capture fish for tagging studies, but these were not directly assessing the effect of capture and release on the fish's response or on post-release mortality. Indeed, fishwheels have been used in such instances as means to capture and release fish with the assumption of minimal injury or capture stress. Fishwheels are mostly effective between dusk and dawn (Cook et al. 2014) and captured fish will remain in holding tanks until they are checked, usually the next day. Therefore, aside from trauma and stress associated with the rapid encounter (e.g., < 30 s), confinement stress and potential crowding experienced during prolonged holding is likely the most detrimental impact of fishwheel capture (see sections 2.5.1 and 2.5.3 on crowding and confinement). There have been indirect assessments of the potential capture and handling mortality associated with fishwheel operations (Underwood et al. 2004; Bromaghin et al. 2007).

Trawling - Over 50% of the world's total marine catch is harvested using towed fishing gears (i.e., Danish seines, dredges and otter and beam trawls) and their poor selectivity combined with broad spatial deployment results in considerable potential for cumulative effects of different aspects of the gear on injury, stress, and mortality (Broadhurst et al 2006). Targeting primarily demersal species, Pacific salmon are not targeted using trawls but defining predictors of mortality in trawl bycatch fishes can help elucidate potential fishing-induced sources of mortality from other gears. For example, the negative impact of gear towing speed on fish condition and mortality as well the relationship between fish size and mortality in trawls may be relevant considerations for other fishing gear types, like purse seines (Van Beek et al. 1990; Suuronen et al. 1996).

2.6 HOOK AND LINE FISHING

2.6.1 Hook and Line Terminal Gear

There have been several thorough reviews of the factors that influence mortality associated with recreational fishing aspects of hook and line fishing (Muoneke and Childress 1994; Cooke and Suski 2005; Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007). The point (or points) of contact between the hook and the fish can dramatically influence the outcome of a fisheries interaction. As a result, there is a substantial body of research on how various aspects of hooks (e.g., size, type, hooking location) and terminal gear cause injury and contribute to post-release mortality, both in salmon and in numerous other recreational important species.

2.6.1.1 Bait / lure

Bait is a live (or dead) animal (or piece of an animal) that is attached to the line (often affixed directly to a hook) to attract fish using both visual and chemosensory cues, whereas lures and flies, are artificial attractants that uses colours and shapes to attract the fish (although some artificial lures are coated with olfactory attractants). One of the most commonly mentioned factors affecting mortality rates in hook and line fisheries is whether lures or baits are used. There have also been many comparisons made between specific bait and lure types (Payer et al. 1989; Clapp and Clark 1989). Many reviews have addressed bait and lure choices in relation to mortality and research has shown significant differences in hooking effects as a result of whether lures or baits are used.

The consensus in the literature is that lures and flies usually result in more superficial hooking locations and less frequently result in deep hooking (i.e., hooked in the esophagus or adjacent organs). Consequently, lures and flies are easier to remove and cause less severe injury to the fish (Arlinghaus et al. 2007, 2008; Muoneke and Childress 1994). Arlinghaus et al. (2007) cover many reviews on a variety of species, and cite findings from Diggles and Ernst (1997) that found bait fishing for yellow stripey (*Lutjanus carponotatus*), and cod (*Epinephelus quoyanus*) resulted in mortality rates of 5.1%, whereas lures resulted in a mortality rate of 0.4% with less bleeding and severe organ damage. Similarly, Pauley and Thomas (1993) found cutthroat trout (*O. clarkii)* mortalities to be much higher for bait-fishing than for lure-fishing. Gargan et al. (2015) found that Atlantic salmon had higher survival when captured by flies than when captured by lures. Arlinghaus et al. (2008) assessed the relationship between bait/lure size and hooking location, and found that the likelihood of northern pike being hooked in a critical location (gills, esophagus) was much higher with larger baits and lures, and that natural baits led to more frequent deep-hooking. Alós et al. (2009) compared the use of worms and shrimp in a mixed-species recreational fishery and found that catch rates were equal for both baits but that the use of worms led to a greater proportion of deeply hooked fish. Because deep hooking is strongly associated with mortality, Alós et al. recommended shrimp be used as bait. Hühn and Arlinghaus (2011) combined results from previous reviews and studies on hooking mortality, and found that lure-caught fish generally had a lower chance of mortality (11.4%) than fish caught using bait (25.9%). For salmonids, the difference in mortality between lure-caught and bait-caught has been similarly distinct in the literature (11.6% lure, 27.0% bait) based on 116 separate mortality estimates. Indeed, salmonids are more likely to swallow natural baits than artificial lures, leading to deep-hooking (Muoneke and Childress 1994; Warner 1976; Warner and Johnson 1978; Taylor and White 1992).

2.6.1.2 Hook type

The type of hook that is used will influence the severity of the hooking injury experienced by the fish, the length of handling time (because of differences in de-hooking times), and the anatomical hooking location (Arlinghaus et al. 2007). Hooks are designed for catching fish but can be modified to reduce the probability of injuring fish. For example, removing the barb from a hook is a common strategy believed to reduce the tissue damage experienced by fish that are hooked. Without the barb, the hook is also easier to remove from the fish's tissue (Meka 2004). Hühn and Arlinghaus (2011) reported in their review paper that salmonid mortality from barbed hooks was 15.1% compared to 8.6% from barbless. The effects of barbs on mortality differs among species, partly because of differences in mouth morphology, and so studies do not always find significant differences in mortality between barbed and barbless hooks (e.g., Matlock et al. 1993; Dubois and Kuklinski 2004; Dubois and Pleski 2007). Nonetheless, decreased injury and unhooking time can usually be expected when using barbless hooks, although the rate at which fish are landed will typically decrease without the use of barbed hooks – the purpose of the barb is to make it more difficult for the fish to become unhooked while it is being reeled in (Schaeffer and Hoffman 2002).

Hooks come in different configurations and may be single, double, or triple (i.e., treble hook) pronged. Treble hooks can be more injurious because they have three points of entry; correspondingly, they are also more difficult to remove than single hooks, which have only a single point of entry. However, treble hooks have a wider base and are therefore more difficult for fish to swallow, and Klein (1965) suggested that treble hooks are an effective tool to reduce deep hooking of fish. Lures often have multiple sets of hooks. Cox-Rogers (2004) found no evidence that tandem hooks increase mortality relative to single hooks when tested on herring plugs in a coho salmon fishery.

Circle hooks have recently grown in popularity in some marine fisheries. Circle hooks are distinguishable from J-hooks in that they have a hook point angled at least 90 degrees towards the hook shank (Serafy et al. 2012). With this shape, the hook becomes less likely to lodge deeply in the esophagus, gullet, or gills of the fish (Cooke and Suski 2004). Circle hooks are primarily used in marine fisheries (e.g., Prince et al. 2002; Graves and Horodysky 2008) but are also becoming popular in fresh water because of their conservation value. However, circle hooks can in some cases have lower landing/catch rates than J-hooks and require subtle alterations to angling technique in order to be effective for hooking and landing fish (Sullivan et al. 2013). Similar results were found for marine commercial troll fisheries with a reduction in injury and catch rates for circle versus J-hooks (Orsi et al. 1993).

2.6.1.3 Hook size

Hook size can influence the severity of injury, anatomical hooking location, and mortality (Muoneke and Childress 1994). Hook size is thought to have an effect on mortality via its effect on hooking location (Arlinghaus et al. 2007). The relative importance of hook size in mortality is dependent on fish size, but, like the type of hook used, is species-specific because it depends on the mouth morphology of the fish. For hook size in relation to injury it is assumed that injury severity would be higher for smaller fish combined with larger hooks, due to the large hook to body size ratio (Muoneke and Childress 1994; Robert et al. 2012). However, small hooks also tend to be injurious to large fish because they are easier to swallow and become lodged in critical locations such as the gills. Stein et al. (2012) assessed the effects of hook size on mortality in bonefish and did not find a significant effect on mortality (though there was 100% survival in the study). Similarly, Savitz et al. (1995) did not find a significant relationship between hook size and mortality of sport-caught coho and Chinook, nor did Taylor and White (1992). Cooke and Wilde (2007) identified a few studies where hook size was considered significant: in Carbines' (1999) study on blue cod (Parapercis colias), and Cooke and Suski (2005), with the latter in reference to circle hook effectiveness being linked to the entire hook fitting in the mouth.

2.6.1.4 Hook location

The physical location on the body where the hook connects with the fish is, in general, the most important predictor of post-release mortality in hook-and-line fisheries (Muoneke and Childress 1994). Many studies addressed the most commonly hooked locations, as well as the resulting injury severity and mortality rates associated with each (Lindsay et al. 2004). If hooked in an internal organ or the gills, the probability of survival tends to decrease significantly. Hooking location can range from superficial and low impact (in the lip or jaw) to fatal (gills, esophagus, critical internal organs, eyes; Arlinghaus et al. 2007; Aalbers et al. 2004; DuBois and Kuklinski 2004). Mongillo (1984) identified critical hooking locations in salmonids to be the gills, esophagus, eyes, and tongue. Furthermore, he identified that variations in gear can influence hooking in those critical locations, showing that using worms as bait led to up to 60% probability of hooking in a critical location, whereas flies and artificial lures, led to critical hooking at rates of 30 and 15%, respectively. Cowen et al. (2007) built on Mongillo's research and added the roof of the mouth to the list of critical hook locations that tend to lead to negative outcomes. Recently it has been determined that for Nicola River Chinook salmon, the corner or hinge of the mouth where the upper and lower jaw come together can also be a critical location, as there is a major artery that can be punctured, so it is often best to leave the hook in place (cut the fishing line) to avoid very heavy bleeding (R. Bailey, DFO, Kamloops, B.C., personal communication). Wertheimer (1988) cited hooking location as one of three key variables (other two being fish length, and lure type) that drove mortality of commercial troll-caught Chinook salmon. The highest rates of mortality occurred in fish hooked in the gills (Wertheimer 1988).

Another component of hooking location oft-cited as responsible for mortality is deep-hooking, defined as hooking in the throat, esophagus, gills, or gullet. Hooking in these locations can puncture veins or arteries, leading to severe blood loss, and/or damage vital organs. Deep hooking is often accompanied by bleeding, which can be an indicator of injury and short term post-release mortality. Hühn and Arlinghaus (2011) described a relationship between natural bait and mortality rates, particularly among salmonids, whereby there was a propensity for natural baits to lead to ingestion or deep-hooking. When a fish becomes deeply hooked, handling time for removal (and air exposure), and severity of injury and bleeding are increased, which lead to a much higher likelihood of mortality (Hühn and Arlinghaus 2011; Arlinghaus et al. 2008; Payer et al. 1989; DuBois et al. 1994; Person and Hirsch 1994). Stein et al. (2012) also reviewed the severity of hook location and deep-hooking, summarizing from many sources that deep-hooking is one of the most important predictors of hooking mortality (Arlinghaus et al. 2007; Bartholomew and Bohnsack 2005; Cooke and Suski 2005; Cooke and Wilde 2007; Muoneke and Childress 1994).

2.6.2 Handling Gear

Depending on hooking location, removing the hook might cause more injury/bleeding than cutting the line and leaving it in, while the removal process would also increase handling time. Mason and Hunt (1967) found high mortality of rainbow trout from which the hook was removed compared to those from which the line was cut. Fish are capable of surviving with lures and hooks in the mouth and passing them over time (Tsuboi et al. 2006; Dubois and Pleski 2007; Pullen et al. 2016; Weltersbach et al. 2016). The physical injury and extra handling and air exposure time associated with removing hooks lodged in difficult locations can dramatically decrease the probability of a fish surviving the fishery encounter (Fobert et al. 2009).

Fish have a protective mucous layer with antimicrobial properties, which can be damaged by materials such as nets (Barthel et al. 2003), gloves, or hands. Thus, handling fish should be minimized to avoid removing the protective mucous, and any necessary handling should ideally be carried out with soft, smooth, and pre-wetted handling gear. Nets or gloves can also remove scales or cause fin fraying. These physical and physiological damages can result in increased probability of infection, disease, and delayed mortality. However, nets are important tools for reducing the landing time in recreational fisheries so that fish are not excessively exhausted. They are also useful for retaining fish while unhooking so that fish are not subjected to excessive manual handling. Soft rubber or rubber-coated knotless nets are the best tools for minimizing handling and rapidly releasing fish. Anglers may benefit from tools such as needle-nose pliers or forceps for quickly removing hooks but should avoid tools such as lip gripping devices or gaffs when landing or handling fish. Butcher et al. (2010) conducted an angling study with Eastern sea garfish (*Hyporhamphus australis)*, where they compared injury and scale loss between different handling experiences using MRI so that even fine scale compression/bruising damage could be detected. They assessed dry hands, wet hands, cloths and pliers for handling (cloths would be analogous to gloves, and pliers for hook removal would mean that the fish was not handled directly at all). Pliers resulted in the shortest handling times and the least scale loss and injury. Dry, bare hands were associated for longer handling times and higher scale loss and injury (due to the fish being dropped during handling). Butcher et al. 2010 also advocated for the use of knotless landing nets, because knotted nets can cause abrasion, injury, and mortality (Butcher et al. 2008, 2010; Lestang et al. 2004; Barthel et al. 2003).

2.6.3 Major Hook and Line Fishing for Pacific Salmon

There are many different techniques developed for salmon fishing, most of which are distinguished by specific rods, lines, or lures/baits. The type of terminal tackle used, the response to tackle by the fish, and the physical environment the fish are in will all influence the stress and injury response. Here we outline some of the important hook and line fishing techniques used by salmon fishers in the Pacific Region of Canada.

Trolling for salmon is one of the most common forms of fishing (Cox-Rogers 2004). It involves drawing one or more lines with bait or lures through the water, usually in the marine environment behind a boat, but can also be done in fresh water. Many angling studies assess the impact of trolling on salmonids, where the key variables are usually related to terminal tackle choices (see bait/lure, hook type). The effects of trolling capture on salmon are typically more comparable to those resulting from recreational angling methods than to other commercial methods (i.e., using nets). In commercial trolling operations, a vessel simultaneously fishes multiple lines and/or hooks baited with lures or bait fish. The responses of salmon to being caught in troll fisheries have been documented and summarized by Ricker in 1976. There has been relatively little recent research directly on rates of post-release mortality for troll caught salmon but survival in fish caught by hook and line is generally assumed to be high compared to other commercial methods (e.g., trawl captured [Suuronen et al. 1996], gill net [Murphy et al. 1995]). However, mortality rates in studies of commercial troll fisheries have been shown to be influenced by both hook type (Carruthers et al. 2009) and location (Murphy et al. 1995). The trolling speed or current speed in conjunction with hook time, could influence the level of exhaustive exercise a fish can experience.

Bar fishing involves casting some gear that includes a weight, appropriate to the river velocity, to "anchor" the gear in a stationary position and a leader of varying lengths with a buoyant lure or bait and hook that settles into a relatively stationary position in the water columns. In bar fishing, the rod is typically then be secured to a rod holder stuck in the gravel at the river edge while the angler waits until a fish swimming upstream encounters and actively bites the bait/lure hook. Similar to troll methods it is possible to have more than one line-out, impacting the capture time per fish. The effect of such a capture experience on the fish will depend on a variety of factors already discussed above (hook size, angler technique/experience, landing gear, etc.). The hook location and resulting injuries have been touted as the main driver of post-release mortality associated with bar fishing (DFO 2002)

In contrast to the hands free trolling or bar fishing more active participation from the angler is involved in the different types of drift fishing (e.g., mooching, jigging, fly fishing, bottom-bouncing). For example, mooching involves manually moving the bait or lure through the water, similar to jigging. Common mooching for salmon occurs in marine waters from boats with a line angle less than 45° to the water (Cox-Rogers 2004). Mooching is effective when feeding salmon are discovered because it allows the fishers to target the school. A direct benefit of drift fishing in contrast to trolling or bar fishing is that the fisher is more likely to know when a fish, regardless of size, is on the line and can respond immediately. Shorter capture times limit capture stress and depredation events. The downside of mooching that the common use of herring cut-plugs with the potential for more severe hooking injuries from bait than lures (e.g., Cox-Rogers 2004).

Fly fishing involves a using a type of lure called a "fly" that is made from natural (e.g., feathers, fur) or artificial material but mimics the shape of a prey species such as insects or baitfish. This method uses a weighted line and a specialized fly rod for casting. The fish actively takes the fly. The hook size is typically smaller than other fishing methods, resulting in more favourable hook locations and lower injury impact. However, a potential drawback with fly fishing is the lighter gear used with the potential for increased capture times and associated stress if the fish caught is larger.

Not all methods of rod and reel fishing involve the fish actively taking the hook. Methods that involve a drawing the leader line across the fish and hooking the fish in outer mouth. These methods are commonly referred to as bottom bouncing or flossing. The major difference in comparison to other hook and line methods is in hook location, which tends to consistently occur on the maxillary (jaw) on the side of the fish opposite to where the angler is positioned (Thomas and Cahusac 2012).

2.7 INTRINSIC FACTORS

In this section we examine how the existing characteristics and physiological status of a fish prior to capture, or intrinsic factors, can influence the likelihood of FRIM. For each factor we have provided the following:

1. a general *overview of mechanism* linking the factor to a fish's response to capture and ultimately to its likelihood of fishing-induced mortality;
2. an assessment of the *relevance* of each factor in relation for different types of fishing mortality (e.g., escapee, short-term release);
3. a summary of the strength of *evidence* (volume and consistency) for fish in general and for Pacific salmon;
4. an assessment of the likely (relative) *magnitude* of effect of the factor on mortality; and finally
5. a summary of *key considerations* such as interaction with other factors and caveats for use of information.

Ideally, literature support for types of interactions among factors (i.e., antagonistic, synergistic, and additive) would be helpful, but this information is lacking in nearly every case.

2.7.1 Physiological Condition

Overview of mechanism: If an individual fish is in a physiologically compromised state (e.g., heightened stress or strain on the immune system, cardiorespiratory system, or endocrine system) prior to the capture event, the individual may be more likely to experience FRIM. In any study of FRIM there is some amount of unexplained variation; two apparently similar fish exposed to seemingly identical fisheries stress may have different physiological responses and survival outcomes. Inter-individual differences in internal physiological state are likely the root of this observed variation (Raby et al. 2015b). However, due to the challenges associated with measuring baseline (i.e., pre-capture, non-stressed) physiological variables, there is limited evidence available to understand the mechanisms of how pre-capture physiological state affects survival during capture and post-release.

Adult migrating Pacific salmonids undergo a complete shift in their osmoregulatory physiology as they transition from salt to fresh water. Inter-individual variation in osmoregulatory status is a potential predictor of differences in the capacity to respond favourably to stress in marine or freshwater environments (i.e., an efficient recovery to pre-stressor state; Wagner et al. 2006). Although high rates of mortality have been observed for Pacific salmon captured and released soon after moving into fresh water (Vincent-Lang et al. 1993; Donaldson et al. 2010, 2011), the mechanisms driving susceptibility to post-release mortality remain poorly understood, and the contributing role of osmoregulatory state cannot easily be isolated from other factors (e.g., water temperature) when comparing rates of mortality among studies.

The cardiorespiratory status of a fish at the time of fisheries capture may be an important intrinsic factor in some cases. Successful recovery from fisheries capture involves repayment of an oxygen debt (termed excess post-exercise oxygen consumption; EPOC – See Lee et al. [2003]) incurred by exercise and, in many fisheries, air exposure. Elevated water temperatures (e.g., > 16°C) may significantly reduce aerobic metabolic scope in some species and/or populations of salmon, which would reduce the capacity of the fish to repay any oxygen debt during EPOC. If catch-and-release results in a sustained post-release stress response (e.g., because of an injury or infection), aerobic scope may be further reduced and potentially contribute to FRIM, especially at high temperatures (Eliason et al. 2011; Cooke et al. 2013). There are also natural features of river migration that are physically taxing for the animal. For example, areas of high water velocity that must be traversed (e.g., Hinch and Rand 2000; Burnett et al. 2014a) and that may incur a short-term reduction in cardiorespiratory capacity in the form of EPOC. It is possible that fish may be particularly vulnerable to FRIM if fish encounter gear (i.e., drop off or release) during one of these periods of natural exhaustion.

Individual, population, or annual variability in the energetic status of the fish may also influence their ability to respond to capture stressors. However, very little work has been done in this area. Parker et al. (1959) did surmise that the feeding status of coho and Chinook salmon in marine environments was related to a more aggressive and sustained fight response. The added activity level led to high levels of plasma lactate and higher mortality compared to salmon caught in fresh water. Salmon do have the capacity to repeat swim activity without full recovery, but if lactate levels do exceed certain thresholds (> 10 mmol $\cdot l^{-1}$) then repeat performance is lower (Farrell et al. 1998).

The majority of physiology studies addressing FRIM completed to date have focused on understanding the physiological response to the capture event itself rather than the pre-existing physiological state at time of capture. This includes a focus on understanding how fish respond to each component of the capture event (Gale et al. 2013) as well as understanding the time-course of physiological recovery (e.g., Donaldson et al. 2013; Raby et al. 2015d), and how physiological condition affects survival days and weeks post-release (e.g., Donaldson et al. 2011, 2012). This work is similar in nature to post-capture analysis of fish vitality using RAMP assessments to predict the fate of fish post-release (Davis 2002). Vitality research will likely be important for describing the cumulative impacts of multiple stressors (Raby et al. 2015b) on the susceptibility of fish to FRIM.

Due to the difficulty of measuring pre-capture physiological condition, there is currently a limited amount of information available to understand the mechanisms by which pre-capture condition influences FRIM. One approach is to look at percentage change in physiological samples collected over a brief holding period (e.g., 30-120 min; Thompson et al. 2008 Raby et al. 2015d). Another approach is to collect an initial biopsy immediately upon capture in an attempt to collect data as close to baseline as possible (e.g., baseline samples collected in Donaldson et al. 2012) and couple these samples with telemetry (reviewed in Donaldson et al. 2008). The biotelemetry studies that have addressed pre-capture condition and fate have some promise in linking physiology condition to FRIM. Cook et al. (2014) investigated how total stress responsiveness was related to migration success in migrating sockeye salmon by rapidly drawing blood from fish captured via fishwheel (< 2 min from initial contact with fishing gear) and then again 30 min later. Fish were then released with a radio-transmitter and tracked to spawning grounds. They found that the individuals with more pronounced stress reactions (larger net increase in cortisol) were more likely to experience FRIM (Cook et al. 2014). Other studies include: correlates of osmoregulatory preparedness, energy status, reproductive state, and immune response (e.g., Cooke et al. 2006; Crossin et al. 2009; Donaldson et al. 2010); however, while this type of work has shown promise in describing mortality patterns, the results have not always been consistent with respect to which physiological variables are correlated to survival (e.g., Donaldson et al. 2011) and even in the direction of mortality in the case of immune transcriptional responses (Hammill et al. 2012). In addition, in these studies it is impossible to identify individual mortality events caused primarily by capture and handling associated with biopsy and tagging versus those that constitute natural mortality. This work was designed to test for the associations among various physiological states and natural mortality, and not to test for the interaction of fish condition and fisheries capture. As such, the mildest-possible capture and handling techniques were used in the majority of these studies. Nevertheless, all capture techniques involve substantial stress and at least some injury to the animal, so interpretation of these results requires maintaining the assumption that the incremental stress caused by capture and release may contribute to the observed differential survival associated with differences in physiological state.

Interestingly, an analysis of recaptured sockeye salmon biopsied and radio-tagged did not detect a bias towards fish based on the condition at release (Cooke et al. 2009), suggesting poor-condition fish were no more likely to be captured using standard commercial fishing gear than were good-condition fish. This is potentially in contrast to other natural predators for which preferential selection of salmon prey can be based on physiological condition or disease state (Miller et al. 2014).

Relevance: The intrinsic physiological condition of the fish is relevant to mortality components associated with the acute and delayed stress response. The capture of an already stressed salmon may shorten the time necessary for the capture-stressor to elicit a physiological response sufficient to lead to FRIM. Similarly, additional stressors associated with a fisheries encounter may limit the ability of fish to recover, resulting in a state of prolonged stress, potentially leading to problems of infection and changes in behaviour (discussed further in sections 2.7.5 and 2.3.3). We are not aware of a connection between pre-capture physiological condition and the magnitude of injury that results from a fisheries encounter.

Evidence: Overall, there is ample evidence from laboratory and telemetry studies that the pre-capture physiological condition of a fish will influence its physiological reaction to the capture-stressor and influence FRIM. However, due to logistical constraints, there is limited work that has directly tested pre-capture physiological condition against different aspects of fisheries encounter experience in order to assess its importance as a factor in FRIM.

Magnitude: The results of the aforementioned biotelemetry studies for which the existing physiological status can be associated with post-release survival did not indicate there was a large effect based on the amount of total variance explained using physiological variables (e.g., Cooke et al. 2006; Miller et al. 2011). The effect of pre-capture physiological condition is usually defined as a threshold, whereby there is much individual variation and certain individuals may be in a more physiologically compromised state (and thus, less likely to survive a fishery encounter) compared to others. However, the masking effect of stress associated with the capture event itself may supersede the observed pre-capture physiological condition, thus, having a greater effect on survival.

Key considerations: Key factors that likely have a role in determining pre-capture physiological condition include intrinsic factors such as species (e.g., Donaldson et al. 2013), size, reproductive maturity, osmoregulatory status (i.e., are the fish in salt water or fresh water or in transition), and environmental conditions that the individual experienced including water temperature, dissolved oxygen, turbidity, and velocity. In addition, the research on physiological condition, even if performed on surrogate species, is useful for interpretation of research quality, or utility of other work related to FRIM (Cooke et al. 2013).

2.7.2 Size and Age

Overview of mechanism: The relationship between fish size and FRIM is complex; many studies across several taxa have assessed the relationship between fish size and mortality, but results are often contradictory within and among species. Fish size has been shown to be both positively and negatively correlated with mortality, and is linked strongly to other handling or gear-related factors, particularly because fish size can dictate the severity of the injuries incurred. The relationship between fish size and FRIM has been linked to handling techniques, net mesh size, hook size, anatomical hooking location, catch composition, catch density, and salinity (see reviews Chopin and Arimoto 1995; Broadhurst et al 2006;). Within salmonids, a good deal of information exists on rainbow trout, Chinook salmon, and coho salmon, with lesser amounts of information on sockeye salmon, pink salmon, and chum salmon. One potential reason for the confounding information on the effect of body size on FRIM is scaling effects of fish and exhaustive exercise; larger fish have higher anaerobic capacity relative to body size than do smaller fish. Consequently, larger fish are generally capable of performing more burst swimming activities, increasing potential for escape from fisheries gear. The downside of higher anaerobic capacity is that increased anaerobic expenditure results in a greater oxygen debt that must be repaid during the post-exercise recovery period (EPOC; Kieffer 2000), which may be particularly challenging at warmer temperatures for larger salmonids (Clark et al. 2012).

Relevance: Results of studies assessing size in relation to mortality are variable, thus, the true relevance of size as a metric when considering FRIM in Pacific salmon is tenuous. The fact that size is an easily measured variable may underlie why it is commonly assessed as a factor in fisheries-induced mortality literature. Size plays an integral role in how fish will interact with gear, as gear is usually optimized to target specific fish sizes. In a gill net fishery for example, the mesh opening and filament size of a net will be optimized to catch a target species. Indeed, the most obvious effect that size has on mortality is the relationship it has to the gear type and the resulting effect on injury severity; if smaller or larger bycatch species encounter the net, they will face different effects as a result of their encounter than would the target species. In a trap or seine net fishery, catch composition and catch density would likely relate to the link between fish size and mortality. The fate of the fish inside the net may depend on their size in comparison to the surrounding bycatch, which could, in turn, affect their position within the net and the injuries that occur during gear hauling or fish release.

The most often cited size-related examples pertain to the relationship between size and hook-related effects (e.g., Orsi et al. 1993). It appears that fish size influences where and how it interacts with the hook. For example, Nuhfer and Alexander (1992) found that larger brook trout were more likely to become hooked in the gills or esophagus, both are severe hooking locations where potentially fatal injuries can occur. Size may also be positively correlated with aggressive behaviour, leading to more severe injury (Cox-Rogers 2004; Muoneke and Childress 1994; McNair 1999). In contrast, fish size and mortality may be negatively correlated with hook size. As the hook:body ratio increases, so does the potential for injury and subsequent mortality (Muoneke and Childress 1994; Diewert et al. 2002; Gjernes et al. 1993). The relationship between hook size and fish size can also vary within and among species. In addition to fish size affecting the interaction with a specific gear, larger fish may be more difficult to handle, increasing de-hooking and/or sort times and the resultant stress experienced by the captured fish. Wydoski et al. (1976) found that smaller rainbow trout experienced less hooking stress than did larger trout.

Evidence: Overall, there is a great deal of evidence supporting the relationship between size and FRIM, perhaps owing to the ease of measurability of size as a variable. Further the range of gear types available to fishers that enable size selectivity (e.g., mesh dimensions and hook size) facilitates research regarding the influence of size on FRIM. The main concern with the evidence is that the response is very much dependent on the specific environment or gear type encountered, making generalizations difficult.

Magnitude: Since the results are so variable and dependent on fish species, environment, and gear, it is also difficult to generalize the magnitude of the effect that size has on FRIM.

Key considerations: Key interactions between fish size and mortality are with gear type/gear variation, handling ability, stress physiology, and to a lesser extent, salinity. For example, Wertheimer (1988) reported that small Chinook had higher mortality rates than did large Chinook in a commercial troll fishery. However, when a similar study was repeated the following year the size effect did not persist for all size categories, only for the small sub-legal category (Wertheimer et al. 1989). There is also the potential for interaction between fish size and post-release behaviour; larger Chinook salmon released after capture dove deeper than did small individuals, potentially effecting re-capture rates (Candy and Quinn 1999). Literature on non-salmonids suggests that environmental variables are important considerations. In a simulated trawl experiment with lingcod, water temperature, air exposure duration, and tow time were shown to have a greater effect on mortality of smaller fish (Davis and Olla 2002). Salinity was shown to have a size-specific effect on striped bass in fresh water. Hysmith et al. (1993) found that mortality increased with fish size in fresh water with salinities of 0.5 to 4.2 ppt.

2.7.3 Species

Overview of mechanism: Differences among fish species can result in variable susceptibility to FRIM. Cooke and Suski (2005) concluded that although some general “rules” exist (e.g., more stress is worse than less stress), there are inherent differences in morphology, anatomy, life-history, and physiological tolerances that lead to inter-specific variation in responses to fisheries interactions. The most conspicuous differences among species are size and shape differences that can cause species-specific susceptibility to injuries depending on gear type (Davis 2002). There is less known regarding among-species differences in physiological response to FRIM. In cases where among-species differences in survival or physiological tolerance (unrelated to body size or shape) have been found, the underlying mechanisms are usually unclear. Similarly, the extent that comparison between-species (i.e., only two species) can be generalized to comparisons among other species requires caution (Bartholomew and Bohnsack 2005; Broadhurst et al. 2006). Indeed, reported species differences in survival for marine tagged fish suggest there may be variability in response to capture and handling stressors (Reviewed in Drenner et al. 2012).

Current literature comparing FRIM among species generally focuses on species with markedly different morphology, behaviour, or physiology (e.g., flatfish vs. round fish, active pelagic species vs. less active benthic species); however, differences among and within Pacific salmon species are comparatively subtle. As a result, limited evidence suggests one species of Pacific salmon will react to and recover from fisheries interactions in a fundamentally different way than would another. Anecdotal cases in which one species is apparently more prone to stress or injury during capture could be explained by differences in maturation status or size-at-capture rather than by an innate species differences in stress response. Moreover, while considerable knowledge has been developed about physiological or behavioural differences among species or populations, these differences may have variable influence on FRIM. For example, sockeye populations that undergo long migrations will have different body shapes compared to those that have short migrations (e.g., Chilko vs. Harrison; Crossin et al. 2004). Once secondary sexual characteristics are developed, among species differences in morphology become more pronounced (e.g., the large humps on male pink salmon). However, most fisheries harvest and thus FRIM occurs in the marine environment and shortly after freshwater entry when secondary sexual characteristics have yet to develop. Timing of migration and fish behaviour during migration varies among species and populations based on specific adaptations relating to migration distance, species size, and life history (Donaldson et al. 2014). These differences are generally accounted for in the timing of fisheries, however energetic status and morphology have the potential to influence susceptibility to FRIM.

Relevance: In a fisheries context, species and population differences are likely to play some role in survival or mortality due to species specific behavioural and physiological characteristics. For example, as noted in section 2.7.2, there are differences between coho and Chinook in their size-related mortality, possibly due to the more aggressive feeding behaviour of the former. While research in this area is limited, it is reasonable to assume that similar species-specific differences in FRIM do exist.

Evidence: There are a few comparative studies reporting differences in FRIM between species, under different fishing scenarios (e.g., Cox-Rogers et al. 1999). The evidence pertaining to the mechanism behind species differences is more sparse but it is typically related to differences in morphology, behaviour, and physiology. To date, there have been few published studies with provide robust among-species comparisons in FRIM in Pacific salmon (i.e., same fishing gear and controlling for location and maturation status), and it remains unknown whether some of the subtle physiological differences among species and populations (e.g., Eliason et al. 2011; Raby et al. 2013; Donaldson et al. 2014) would have significant effects on recovery from capture-stressors. Thus, while we do know that species differences exist in the response to capture-stressors, less is known about repeatable among-species patterns in susceptibility to FRIM. Therefore it is difficult to provide any generalizations across fishing contexts not directly linked to each study.

Magnitude: Differences in species tolerances and behaviours have been shown to impact survival under different scenarios. However, the magnitude of variability in FRIM reported for different species has been modest to date, based on Hühn and Arlinghaus (2011) review of 213 separate mortality estimates for 11 species of salmonidae. There is a lack of direct comparative studies on Pacific salmon to draw strong conclusions.

Key considerations: Species and populations can respond differently to environmental and fishing-related stressors (Raby et al. 2013; Donaldson et al. 2013; Havn et al. 2015; Robinson et al. 2015). The magnitude of variation may be related to a number of factors, including life-history traits, geographical location of stocks, and migration timing. For example, population level differences are likely to be observed with respect to physiological tolerance to elevated water temperatures (Eliason et al. 2011). An area of potential concern that is not represented in the literature is the difference in hatchery versus wild response to a similar fisheries stressors (Mongillo 1984).

2.7.4 Maturity and Sex

Overview of mechanism: Fish can encounter fishing gear at different stages of development; stress and injury caused by the interaction may vary as function of their ontogeny. Relatedly, there are physiological differences between male and female Pacific salmon that become pronounced as sexual maturation progresses. Maturity status may influence FRIM through behavioural, morphological, or physiological changes that may confer resilience to capture-stressors. For example, female salmon typically have higher circulating baseline cortisol (a primary stress hormone in fish) than do males, and in one study also appeared to be slower to recover cortisol to baseline levels after a capture-stressor when temperature was elevated (Raby et al. 2015a). Female salmon also invest substantially more in development of gonad mass than do males; when paired with endocrine differences, this factor may translate to increased disease susceptibility in female salmon caught and released in warm water (Raby et al. 2015b). These factors may cause sex-specific differences in the physiological stress response upon capture.

There is very limited information available on the role of maturity or sex on FRIM in fishes that is independent of fish size (Broadhurst et al. 2006). For example, previous work on haddock found no effect of sex on discard mortality (Beamish 1966; Symonds and Simpson 1971). In Pacific salmon, there is mounting evidence that females may be more sensitive to FRIM compared to males during the riverine phase of spawning migrations, although evidence is mostly restricted to sockeye salmon (Raby et al. 2015b). Laboratory and telemetry-tagging studies suggest that females suffer markedly higher mortality during the fresh water migration after capture and handling than do males (Jeffries et al. 2012a; Martins et al. 2012; Robinson et al. 2013; Gale et al. 2014). However, most of the existing evidence is based on experiments aimed at understanding natural mortality patterns, thus, in telemetry studies the capture and handling treatments were typically mild (Martins et al. 2012), while laboratory studies include confinement stress that likely amplified mortality patterns (Jeffries et al. 2012a; Robinson et al. 2013; Gale et al. 2014). The observed pattern of higher mortality rates in females appears to occur primarily at elevated water temperatures (e.g., > 19 °C; Martins et al. 2012), although a sex effect remained apparent in the laboratory at 16°C.

Relevance: Both maturity and sex are relevant to FRIM, however, the extent of the interaction with other fishing factors and fish responses remains difficult to quantify. Maturity is likely relevant to injury-related FRIM in Pacific salmon, while sex-specific differences in stress responses may cause variation in susceptibility to FRIM between males and females. Both maturity and sex are likely more relevant in some locations and fishing gear types than others, but there is an insufficient body of evidence with which to assess their importance as factors in FRIM (e.g., their role in the marine environment vs. in fresh water where most of the sex comparisons have been made).

Evidence: Aside from a relatively extensive discussion of the topic by Raby et al. (2015b), we are unaware of any review papers on FRIM that have considered or discussed sex-specific differences. Evidence suggesting females are more likely to experience FRIM is not always consistent (Donaldson et al. 2008). In general, there is very limited evidence on how maturity is related to FRIM, most likely because the vast majority of fishing occurs in areas where maturation status is fairly consistent.

Magnitude: When water temperatures were 19°C or higher, male sockeye salmon were 1.6x more likely to reach spawning grounds compared to females (Martins et al. 2012). The magnitude of the sex-specific effect in warm fresh water was similar in laboratory experiments (e.g., Robinson et al. 2013; Gale et al. 2014). Overall, this suggests the magnitude of the sex response is magnified at higher water temperatures. In contrast, the magnitude of the maturity response may decrease with proximity to the spawning grounds, as evidenced by the high tolerance for air exposure for salmon intercepted at the spawning grounds (Raby et al. 2013).

Key considerations: The main interaction to consider for maturity is the connection to size and location, the latter being an important consideration for salinity and water temperature effects. Hydrology may also play a role as swimming behaviours in mature fish vary between sexes under conditions of high flow (Burnett et al. 2014b). There is also the interaction between maturation and infection, as the developmental changes associated with sexual maturation in fish can interact with their ability to withstand stress. In many salmon fisheries, sex is not reliably identifiable without analyses of sex steroids via blood sampling, this will pose serious logistic challenges to estimating sex-specific FRIM values.

2.7.5 Pre-capture Injury and Infection

Overview of mechanism: The physical condition of fish prior to capture, which may include wounds, scars, infections, or internal damage, is likely to impede the ability of a fish to withstand the additional stress and injury of a subsequent fisheries encounter. Indeed it is well established that delayed and acute stressors, including fisheries interactions, can cause disruptions to immune function, leaving a fish vulnerable to post-release disease development (Lupes et al. 2006). For example, it is common to observe wounds and surficial infections (likely a combination of bacterial and fungal infections) in captured fish, especially in rivers (Baker & Schindler 2009). Any injury, regardless of origin, becomes a site for potential infection due to pathogen entry or proliferation. In addition, the physiological strain due to blood loss and/or impaired swimming ability can further compromise fish immune response and alter behaviour. Pathogens and consequent disease are likely one of the major mechanisms by which fish suffer FRIM after encounter with fishing gear (e.g., 5-20 days later).

Infections can be very difficult to measure and quantify on live fish in the midst of operational fisheries; however, it would be reasonable to assume that fish that are suffering from an existing infection would experience physiological and behavioural impairment that could affect their ability to avoid, escape, or survive a fishing event. In some cases, infection is very obvious, such as fungus covering the body of the fish; however, in most cases, infection that is not easily observed would need to be determined by histopathological sampling, blood work, and or genomic tools (Miller et al. 2014). Understanding how apparently asymptomatic infection may increase the likelihood of FRIM is an important factor that is the subject of ongoing research.

Several studies have assessed the effects of disease in juvenile salmonids. In a lab experiment, Mesa et al. (2000) exposed juvenile Chinook to the causative agent of bacterial kidney disease (BKD), a pathogen that is known to cause extensive mortality. Researchers applied stressors to see how infected fish responded physiologically, and assess how stress increased the severity of infection and observed levels of mortality. They found that heavily diseased individuals experienced physiological stress in the form of increased lactate and cortisol, and decreased hematocrits and glucose, all of which would affect behaviour and ability to recover from or survive a stressor. The assessment of repeat swim performance of mature sockeye salmon has found that recovery potential was limited in fish that had underlying infections (Tierney and Farrell 2004). Therefore, it could be assumed that predation post-release or post-escape would be higher for fish with underlying pathologies.

Relevance: The poor condition of fish would likely affect most aspects of fish mortality, from the ability to withstand capture stress, inability to escape from the gear, or predator avoidance.

Evidence: Overall, the volume and strength of evidence that pre-existing injury or infection plays a role in FRIM for Pacific salmon is low, and primarily limited to indirect studies, anecdotal observation and plausible arguments. Nevertheless, the underlying physiological mechanism for impairment and mortality exists for this factor to play a role in determining the fate of fish that encounter fishing gear. The majority of evidence pertaining to injury and infection come from outside fisheries discard or catch-and-release literature. There have been several recent and ongoing studies that are examining the role of pathogens and infection in association with fisheries encounters, but these are mostly opportunistic with respect to existing infections or injuries (Art Bass, UBC, Vancouver, B.C., personal communication).

Magnitude: It is difficult to quantify the magnitude of impact this particular factor may contribute to overall FRIM because of the lack of evidence and ability to separate pre-existing injuries from those induced by the current fishery. There are several ongoing studies that are looking at the role of injury, vitality, and migration success for several species of fish captured and radio-tagged in Fraser River (e.g., Bass et al. in press). The results of this work may indicate the degree of concern required regarding pre-existing injuries and/or surficial infections. However, application of this information would require census data in the fisheries on the frequency of injuries and infections that are sufficient to cause a demonstrable reduction in mortality before any statements regarding the magnitude of effect could be made.

Key considerations: Abnormal water temperatures and sudden drastic changes in water temperatures can cause suppression of fish immune function and alter typical pathogen transmission and/or proliferation regimes. Fish that are captured during events characterized by extreme temperatures may have higher likelihood of developing disease as a result of secondary infection, particularly when waters are warm.

2.8 EXTRINSIC FACTORS

In this section we discuss how the external environment of a fish, an extrinsic factor, can modulate the mortality outcome associated with a fishing event. Based on our literature survey, there were six such factors about which some evidence exists in the context of FRIM: water temperature, dissolved oxygen, suspended sediment, salinity, hydrology, and predators. For each extrinsic factor we followed the similar outline to the intrinsic factors above (section 2.7), providing information on mechanism, relevance, evidence, magnitude, and key considerations. We also briefly list other extrinsic factors that could potentially be relevant to catch-and-release (or become relevant in the future) but about which little is known with respect to its effect on FRIM.

2.8.1 Water Temperature

Overview of mechanism: Temperature is frequently referred to as the "ecological master factor" for ectotherms because it has profound effects on fish physiology, behavior, and survival. All fish have an optimal range of temperatures, but optimal temperature may vary depending on what aspect of behaviour or physiological performance is considered. For example, the optimal range of temperatures for growth may be somewhat different (usually lower) than the optimal range of temperatures for swimming performance. All fish have critical upper and lower temperatures at which their cardiorespiratory system is unable to keep up with the oxygen demand in their tissues; temperatures the fish can survive for short periods of time using anaerobiosis but that they must escape to survive. Upper and lower critical temperature thresholds appear to be related to a collapse of aerobic scope (AS, the capacity of the fish to supply oxygen to tissues at a rate greater than required for basic maintenance and survival), and research suggests that the heart may be a key factor limiting aerobic scope in salmonids (Farrell et al. 2008; Eliason et al. 2011; Eliason et al. 2013). All capture-stressors increase oxygen demand and many also simultaneously limit oxygen delivery (e.g., via air exposure, exposure to hypoxic waters during crowding, or constriction of gill ventilation), and this combination of factors can result in immediate mortality or an oxygen debt that has to be repaid after release; the latter would take energy and oxygen supply away from that needed to fight pathogens and swim upstream. Aside from its role controlling the capacity of a fish to supply oxygen to critical functions, temperature can also be associated with FRIM via prolonged stress responses and associated disruption to osmoregulatory functioning, and (perhaps in concert) via increased proliferation of pathogens (Jeffries et al. 2012a,b; Miller et al. 2014).

Evidence suggests that Pacific salmon are locally adapted to their historical upriver migration temperature conditions (Crossin et al. 2004; Eliason et al. 2011). As a result, thermal tolerance and aerobic performance differ, to some extent, among species and populations. This has been demonstrated for coho and sockeye salmon populations where information on aerobic performance and historic temperature records exist (Lee et al. 2003; Eliason et al. 2011; Raby et al. 2016). The limited work on pink salmon suggests that they have a high thermal tolerance consistent with the late-summer migration in the Fraser River (Clark et al. 2011). We are not aware of comparable thermal adaptation studies on adult Chinook and chum salmon.

In general, cool temperatures (e.g., 8-12 °C) are not considered a problem for most populations of Pacific salmon with respect to physiology or behaviour, and these temperatures would be expected to be non-factor with respect to FRIM. This may reflect a bias in the publications towards fresh water research at high water temperatures. Our conclusions regarding temperature effects are driven mainly by fresh water research. Exposure to low temperatures can be beneficial, as demonstrated by radio-tagged sockeye salmon from the Harrison, Weaver and Gates populations that exhibited increased survival for individuals that resided in cool, deep lakes (e.g., Farrell et al. 2008; Mathes et al. 2010). Metabolism decreases with decreasing temperatures, which will conserve energy stores– an important consideration since Pacific salmon cease feeding in the ocean and all swimming, gonadal growth, and spawning behaviors are fueled by endogenous energy stores. Access to cold water refugia can be very important to salmon survival for some populations and species during their spawning migration. Perhaps most relevant to fishing encounters in fresh water is that cool temperatures can slow disease progression (Crossin et al. 2008; Bradford et al. 2010) and access to cold water refugia can benefit survival (Keefer et al. 2009; Mathes et al. 2010; Katinic et al. 2015).

There is very strong evidence that high temperatures are detrimental to migration, reproduction and survival (Johnson et al. 2012), and will interact with fishing to increase mortality (see review by Gale et al. 2013). This is of primary concern given that summer river temperatures have been increasing over the last three decades and are projected to continue to increase along the same trajectory while the frequency of extreme high-temperature events will rise (Patterson et al. 2007a; Hague et al. 2011). The real challenge is separating natural mortality caused by exposure to supraoptimal temperatures from the incremental mortality associated with a fishery encounter that occurs in warm water. In laboratory experiments, this can be done using untouched control groups and in the field, control values (for in-river survival) can be achieved using ocean-tagged controls. A large body of work has focussed on exploring relationships between water temperatures and natural survival using aerobic performance as an indicator. The functional upper critical temperature (functional T_{crit}), or temperature when the fish can survive but only for a short period of time (i.e., < 72 hr) is the population-specific temperature (above the temperature for maximum aerobic scope) that corresponds to 50% of maximum aerobic scope. The range of temperatures at which performance becomes compromised (where aerobic scope apparently begins to decline to between 50% to 90% of maximum AS) varied between 16.5 to 20.7 °C for several Fraser River sockeye salmon populations (Eliason et al. 2011). These functional T_{crit} values from swim performance trials are supported by the following lab and field studies: four studies found that mortality was very high in Weaver fish exposed to 19°C or higher (Crossin et al. 2008; Farrell et al., 2008; Mathes et al. 2010; Gale et al. 2014); Servizi and Jensen (1977) identified 23 °C was as a threshold temp for Early Stuart sockeye salmon (50% mortality occurred at 23 °C after 63 hr at 23 °C); Stellako and Late Stuart sockeye salmon exposed to 21 °C had 100% survival after 48 hr but only 19% at 72 hr (Gale et al. 2011); and Chilko have an especially high functional T_{crit} which is supported by Martins et al (2011) which examined stock-specific survival across several telemetry studies and by Gale et al. (2011) where 100% of Chilko survived 21 °C for the three day experiment.

Though a fish may be able to survive for a short period of time (e.g., 72 hr) at these threshold temperatures (aka functional T_{crit}), latent mortality is expected to be high if fish are exposed to these temperatures and becomes a near-certainty with any additional stressors (e.g., fisheries interaction). There is a surprisingly small temperature range where the risk jumps from affecting fish health, reproduction and/or swim performance, to causing mortality. For example, fish exposed to handling, handling+capture stress, and handling+capture+revival at 16 °C had 100%

survival after 96 hr, while the same treatments conducted at 21 °C resulted in 100% mortality (Robinson et al. 2013).

Relevance: Water temperature influences the magnitude of the energy expenditure during the capture event, the extent of physiological disturbance, the risk of immediate exhaustion-related mortality, as well as the likelihood that the fish will recover from the capture event. Water temperature can also have profound effects on disease development and fish behaviour hours or days after release.

It is important to consider of all the water temperatures encountered by the fish throughout the capture experience and during post-release recovery. For instance, in addition to the stress of being captured, being moved through different thermal profiles can also be physiologically stressful (Donaldson et al. 2008). Many studies addressed the changes in temperature that fish endure during capture and release. Cicia et al. (2012) looked at the effect on elasmobranches of the gradient of temperature change that would be experienced in certain fisheries from seawater capture at a particular depth, to surface water or air temperature. They found that acute thermal stress caused considerable physiological changes, and a reduced thermal gradient from seawater to air could greatly reduce the negative physiological (metabolic and ionic) disturbances (Cicia et al. 2012).

To assess retrieval through a thermocline, or along a thermal gradient, Davis and Olla (2002) conducted a simulated trawl event with lingcod that modified sea temperature and exposed the fish to air. They found that the combined effects of tow time, increased water temperature and air exposure were additive, and showed a dramatic increase in mortality from 8°C water to 20°C (no mortality at 8°C, 100% at 20°C) (Davis and Olla 2002).

Evidence: The evidence for water temperature as a factor in FRIM is very strong, including Pacific salmon. Water temperature has been a recurring theme for several major reviews on commercial discard mortality and capture and release mortality (Broadhurst et al. 2006; Gale et al. 2011; Raby et al. 2015b). Martins et al. (2011) provided temperature and population-specific estimates of catch-and-release survival in fresh water (relative to ocean-tagged controls), although those estimates were based on relatively gentle capture and handling. The evidence in Fraser River sockeye salmon appears to consistently suggest that post-handling mortality is intermediate at temperatures of 15-18°C and becomes extremely high when the water warms beyond 18-19°C (Martins et al. 2011; Jeffries et al. 2012b; Robinson et al. 2013; Gale et al. 2014). Less is known about the exact critical temperature thresholds relevant to FRIM in the other species of Pacific salmon and in the marine environment. Coho salmon exposed to a simulated beach seine experience higher immediate mortality and physiological disturbance at 15°C than at 10°C (Raby et al. 2015a).

Magnitude: Studies that have looked at the effect of temperature on swimming or survival or reproduction have included the following: holding studies looking at natural senescence processes (e.g., Jeffries et al. 2012a); catch and release simulations in the lab (e.g., Gale et al. 2013 and Robinson et al. 2013); or tag–and-release of fish in the wild at different temps (e.g., Farrell et al. 2008; Mathes et al 2010). The magnitude of the effect of temperature on FRIM can be such that 100% mortality occurs, particularly if high temperatures (e.g., >19°C for sockeye salmon) are sustained for several days (Robinson et al. 2013; Gale et al. 2014). Three studies have examined the interaction between temperature and simulated catch-and-release fishing in Fraser River sockeye salmon (Gale et al. 2011; Gale et al. 2014; Robinson et al. 2013). All three studies found that physiological recovery and survival were compromised at high temperatures. The dramatic decline in survival at temperatures approaching 21°C, irrespective of variation in capture and handling techniques, suggest that temperature can play dominance role in predicting FRIM. A similar conclusion was drawn by Dempson et al. (1998) summarizing temperature impacts on post-release survival of Atlantic salmon. This non-linear response has importance implications for scaling the impact of temperature on FRIM. The 21°C threshold value is also relevant to migration blockages for several species of Pacific salmon (McCullough et al. 2001). Water temperature can have a direct effect on upstream migration rate, and this in turn can influence rates of predation or re-capture.

Key considerations: Since temperature has profound influence on all aspects of fish physiology, it is an important extrinsic factor to consider when assessing FRIM. Temperature can exacerbate the negative effects of virtually all other factors. The two major factors to consider are the ability to recover from exhaustive exercise and the rate of pathogen proliferation and infection resulting from injuries (e.g., scale loss to large wounds). The latter is in response to water temperature regulating the development time of pathogens, allowing opportunistic infections associated with injuries to flourish at higher temperatures. The exact nature of these relationships is still being worked out through empirical research and the real challenge will be to partition the incremental mortality associated with the fishing encounter from temperature dependent natural mortality. In addition, there are likely species, and population, differences in thermal tolerance that will be difficult to assess, especially with respect to salt water thermal challenges.

2.8.2 Dissolved Oxygen

Overview of mechanism: Fish are commonly exposed to low environmental dissolved oxygen levels (hypoxia) from both natural (e.g., ice cover in lakes, algal respiration) and anthropogenic (e.g., fish crowded in a fishing net) causes. Oxygen is critical for the survival of fishes since they are dependent on aerobic respiration (oxygen acts as the final electron acceptor in mitochondria to aerobically produce ATP, the energy currency of the cell). If the water surrounding the fish is sufficiently hypoxic, the fish will be unable to obtain sufficient oxygen from the environment to meet their oxygen demand because the arterial blood cannot be fully saturated with O_2 at the gills. Under moderately hypoxic conditions, fish are unable to deliver sufficient oxygen to their working tissues and performance declines (e.g., swimming, reproduction, and digestion become impaired). Below a species-specific critical environmental oxygen tension (P_{crit}), routine oxygen consumption rates decline (Farrell and Richards 2009).

Exposure time to hypoxia is an important consideration in a fisheries setting. At moderate levels of hypoxia, aerobic performance is impaired and prolonged exposure can cause cumulative problems for the fish. When a fish is exposed to oxygen levels below P_{crit}, survival time depends on how much they can reduce their metabolic demands and the amount of substrate available for O_2-independent ATP synthesis (Farrell and Richards 2009). Persistent exposure to hypoxia can result in both sub-lethal effects (prolonged recovery from fisheries interaction, impaired swim performance, reduced migration progression, compromised reproduction) and direct mortality. For instance, exposure to hypoxia during the fishing encounter will increase the net oxygen debt incurred and therefore the time required for EPOC after release.

Relevance: Hypoxia can occur under several scenarios in fisheries. When fish are crowded together and there is low water exchange, the fish themselves will consume much of the oxygen in the local environment, thus generating a hypoxic environment. This is likely to occur in nets (e.g., beach seine, Raby et al. 2014a) or in holding tanks without proper circulation (i.e., some revival boxes). In addition, in any water body with low flow, turbid water or excess mucus sloughing off the fish is likely to be hypoxic.

Evidence: There is strong evidence in fish that hypoxia is detrimental to fish performance, health, and survival (Farrell and Richards 2009). However, there are limited fisheries-specific examples of hypoxia exposure and survival (Davis 2002). In beach seine fisheries for salmon in the lower Fraser River, dissolved oxygen inside the crowded seine can fall 50% below air saturation levels while incidental catch are still being located and released. In coho salmon prolonged exposure to crowding (and falling DO) causes increased physiological disturbance (Raby et al. 2015a) and vitality impairment (Raby et al. 2014a). This is an important area of research that should be investigated to

i. determine the prevalence of hypoxia in fisheries settings (e.g., using hand-held DO meters in fishing nets, holding tanks, water bodies) and to

ii. assess survival and reproductive success associated with various levels of fisheries-related hypoxia exposure.

Magnitude: There is a strong potential for hypoxia to be a major factor, if it exists in a given fishery. Dissolved oxygen is a scalable factor, and time at a given hypoxic level could be converted to generate recommended guidelines. There is potential for fishers to be able to change their practises in response to this factor to improve fish survival (e.g., Farrell et al. 2001b; improve water flow in holding tanks, reduce set times in large catches, etc.).

Key considerations: Although, oxygen solubility decreases with increases in water temperature or salinity, these changes are not considered dramatic over the normal range of salinities or temperatures experienced by Pacific salmon (e.g., a XX % decrease in dissolved O2 from 8-20°C). However, the relationship between temperature and hypoxia is relevant because water can more easily and quickly become hypoxic if it is warmer (e.g., as a result of large numbers of hyperventilating fish). Metabolism increases with increasing temperature, which translates to an increased tissue oxygen demand. Aerobic scope (the oxygen available for activities beyond routine maintenance) declines at high temperature and under hypoxic conditions, so there is strong potential for an interaction between these two factors to strongly affect mortality.

Time is the important factor when considering the relative physiological effects of environmental hypoxia, especially if the hypoxia is caused by oxygen consumption by high numbers of crowded, hyperventilating fish (e.g., when fish are crowded in nets or in tanks without a continuous supply of fresh water). The events in which fish reduce DO levels normally involve bouts of strenuous exercise, such as that typically exhibited by fish when they are forcefully crowded, especially for extended periods. Therefore, although it is possible to scale the impact of low dissolved oxygen conditions by using crowding time as a surrogate for both equilibrium loss and acute mortality, the actual time lines of response would vary as function of the level of exhaustive exercise prior to crowding, the density of the crowding, and the temperature of the water. Fish that survive the acute stress of low dissolved oxygen but suffer equilibrium loss will be vulnerable to post-release mortality.

2.8.3 Suspended Sediment

Overview of mechanism: Suspended sediment (SS) levels can be present in fish-bearing streams at different concentrations as a result of both human activity and natural processes (Servizi and Martens 1991). The effect that SS has on salmonids is well-documented, and its lethality increases with concentration and temperature, and decreases with fish size. While almost all of the documented effects of SS on salmonids and other aquatic organisms is outside of a fishery perspective, it is reasonable to assume that the negative impacts would be compounded in a physiologically stressful event, such as an encounter with fishing gear. The type of biological effects caused by SS (and their magnitude) in salmonids varies by duration of exposure, particle size, particle shape, particle composition, and concentration (Newcombe and Jensen 1996). Fine particles can become enveloped in the cells of the fish and begin to accumulate in the spleen, whereas large particles can cause abrasion and damage to the gills (Martens and Servizi 1993). Prolonged exposure to SS is known to have a negative effect on salmonid growth and survival (Newcombe and Macdonald 1991). The effect of short-term exposure can be relatively harmless if thresholds for SS concentration, size, and water temperature are not exceeded. Smaller fish experience higher lethality from SS exposure than do larger fish, possibly because of inadequate clearance of their buccal cavity, resulting in it becoming trapped/clogged with sediment more easily than a buccal cavity with better clearance (Martens and Servizi 1993).

Relevance: Consideration of SS in a fishing scenario is only relevant in certain locations and with certain types of fishing activities; the presence of SS is associated with fresh water environments, such as the Fraser River, which experiences high turbidity through certain reaches at certain times. In a fishing context, SS concentration is of considerable concern during activities such as beach seining, which stirs up sediment, making the holding/capture environment rich in SS. Turbidity influences the fish's ability to access oxygen (see: air exposure, dissolved oxygen for more info on oxidative stress). High turbidity would mean low oxygen availability. Fish caught in beach seines can be exposed to lengthy sorting times, where they might be sitting in highly turbid (and crowded) water while hyperventilating and actively trying to escape.

Evidence: The influence that SS has on salmonids is very well-documented; however, fisheries-specific examples are almost non-existent. The majority of research on salmonids and SS pertains to juveniles and the remainder is outside of the fisheries context.

Magnitude: Since the effects of SS on salmonid survival are well-known, we can infer that if present in a fishery-scenario that the impact would be measurable and predictable. There are known thresholds of SS concentration, size and exposure time that salmonids are able to withstand.

Key considerations: Much like salinity, SS is a locational feature. Lethality and SS is strongly related to temperature and seasonal differences, as it affects oxygen availability, and increases in temperature require more oxygen consumption. SS can also lower resistance to disease through direct damage to the gills, and worsen disease condition (Redding et al. 1987). Since fish handling can be an introduction to pathogens, exposure to SS post-handling could be detrimental. Fish size is also an important consideration in SS effects, as the ability for a fish to clear SS particles out of their buccal cavity (via 'coughing') depends on the size or clearance of the buccal cavity itself, relative to the particle size (Martens and Servizi 1993). High SS is also associated with water clarity; this could potentially influence the ability of the salmon to perceive predators and for predators to locate impaired salmon that may be vulnerable to predators because of muscle exhaustion and exhaustion-related cognitive impairments.

2.8.4 Salinity (marine, estuary, fresh)

Overview of mechanism: Fish actively maintain their internal ion concentrations at constant levels (a process termed osmoregulation) that differ from those in the surrounding environment. Some fish are adapted to narrow salinity conditions (i.e., stenohaline), whereas other fish can tolerate wide fluctuations in salinity (i.e., euryhaline), with diadromous fishes (those that migrate between saltwater and freshwater environments) being the obvious example of the latter. Regardless, the range of salinity a fish can tolerate and exposure to variable salinities during fishery capture (or post-release) can have sublethal physiological effects and in turn affect fish survival, because, at any given time, a fish's osmoregulatory mechanism is acclimated to a specific level of salinity. Fishery capture itself can also affect a fish's ability to osmoregulate through the effects of cortisol on osmoregulation and/or due to injuries that expose tissues directly to the external environment. Therefore, post-release survival of fish may be influenced by both the osmoregulatory state of a fish and the osmotic environment. This is particularly relevant for estuarine or coastal fisheries where salinity can vary by depth, location, and environmental conditions (i.e., tide, winds, currents), and where fish have the potential to vary in their osmoregulatory state.

Salinity has the potential to influence mortality at multiple points during the fishery capture process. For example, in cases where fishing occurs in stratified environments (e.g., in marine environments near estuaries), fish that are captured from deep, highly saline waters may be exposed to lower salinities while they are pulled up through and released into surface waters that are lower in salinity. Fish may also experience this during sorting on board if the water source used in sorting containers is from surface waters that are lower in salinity. McGrath et al. (2009) examined how variable salinity exposure during the capture process influenced post-release survival. McGrath et al. (2009) found no effects of lower salinity exposure on sand whiting (*Sillago ciliata*) physiology or survival during the capture process, although the authors observed behavioural differences. There are few studies that directly examined whether exposure to different salinities during capture has sublethal or lethal effects; however, the extensive literature on salinity and fish physiology is relevant to understanding how fish respond to and recover from catch-and-release.

Pacific salmon homing towards their natal watershed as they undertake their spawning migration are, while doing so, altering their osmoregulatory physiology in preparation for the transition to fresh water. During this physiological transition, they can encounter numerous fisheries that occur in coastal areas where variable salinities also exist. Cooperman et al. (2010) captured sockeye salmon in the marine environment transferred them to holding tanks with different salinity levels (full-strength sea water, iso-osmotic water, and fresh water) before the fish were released back into the ocean. Sockeye salmon that were acclimated to fresh water had poor survival once released into salt water, providing evidence that fish released into salinity levels that they are not acclimated for can suffer higher mortality. An internal DFO study on coho salmon captured in the lower Fraser River at the upper limit of the salt wedge and near the upper limit of tidal influence did not detect and effect of capture location (DFO 2002). Recent work on sockeye salmon captured via gill net in the lower reaches of the Fraser River similarly failed to detect a strong estuarine signal for mortality (K. Cook, UBC, Vancouver, B.C., unpublished data). This contrasts with the much higher rates of mortality reported for coho salmon caught in estuaries versus those captured upstream of the saltwater influence (Vincent-Lang et al. 1993).

Further evidence of the potential effects of salinity comes from a study that examined the effects of an estuarine trawl fishery on four fish species (Broadhurst et al. 2008). In their study, Broadhurst et al. (2008) found evidence that salinity affected the likelihood of post-release mortality in two of the four species, with higher salinities at the capture site being associated with increased survival. Salinity levels did not have an effect on survival in the other two fish species (Broadhurst et al. 2008). Although the authors were unable to provide salinity-specific estimates of mortality because of the fact that multiple variables were associated with mortality patterns. Nevertheless, the authors attributed species-specific responses in their study to species-specific optimal ranges of salinity.

Relevance: Few studies have directly accounted for the effects of salinity on post-release survival of fish, but there is substantial evidence that suggests salinity can affect the physiology, behaviour, and survival of fish and that the stress induced by fisheries capture can affect the osmoregulatory capacity of fish. Despite the small body of literature directly examining the relationship between salinity and FRIM, the potential effects of salinity on post-release mortality are likely to be dependent on the osmoregulatory state of the fish (e.g., ocean feeding *versus* preparing for fresh water re-entry). These potential impacts are most relevant in environments where salinity varies across time (due to tides, winds, currents) and space (depth, distance to freshwater discharge source).

Evidence: There is only a small amount of direct evidence that salinity can play a role in mitigating the effects of a fisheries encounter. There is also inconsistency with respect to the direction of impact.

Magnitude: With few studies having been conducted to explicitly test the effects of salinity on FRIM, it is difficult to estimate the overall impact salinity would have on FRIM. However, we do recognize that some well-designed empirical research could help reduce some of the current uncertainty.

Key considerations: Salinity is being considered in this review as a potential surrogate for fishery location. As such it has the potential to interact with any factor associated with location. For fishing factors this would include tidal boundary specific fishing gear/method variations. Intrinsic factors would include physiological condition or more specific osmoregulatory preparedness and maturity. Water temperature is also a key consideration given that there is a close association between halocline and thermocline in estuarine waters. There has been speculation on the potential interaction of salmon feeding in marine waters and the potential for greater stress response leading to higher mortality in comparison to non-feeding salmon in fresh water (Parker et al. 1959).

2.8.5 Hydrology (sea state, discharge)

Overview of mechanism: The energy state of water during a fishing event can influence both how the fish interacts with the gear, and its ability to survive after it is released. It can also influence capture time, handling time, and landing methods. If a fishing event occurs in rough sea conditions, for example, it would not only interfere with the gear in the water (net or hook and line), but it would make sorting and handling very difficult, potentially increasing the severity and likelihood of injury (Maeda and Minami 1976). Both Davis (2002) and Broadhurst et al. (2006) cite sea conditions as important and under-represented in the literature in their reviews of key FRIM factors. Variations in gear selectivity with sea state can change the rates of escape for some organisms, especially during gear retrieval (Kynoch and Zuur 1999). "Surging" associated with increased sea state may alter the water flow within the net gear and make it difficult for fish to orient towards selective panels or sorting devices (Suuronen 2005). Fish landed may become stressed, meshed and injured but increased sea state may also cause increased escape during towing and haul-back.

Relevance: Hydrology is likely relevant to those situations where flow, current or wave action can make conditions more difficult for either survival or for fishing. In high flow areas, lack of refugia (slower flowing, back eddies) could be very detrimental to fish survival after a fishing encounter, given that the encounter could leave them exhausted or behaviourally impaired. The most likely relevance is for net fisheries where sorting techniques are dependent on hydrologic conditions. This includes ramping versus brailing or pulling beach seines further ashore for crew safety.

Evidence: There is good anecdotal evidence and plausible arguments for discussing this factor, but it is of limited practical use at this time given the speculative evidence. Most of the evidence that pertains to hydraulic conditions as a FRIM factor revolve around trawl fisheries/towed gear and sea conditions. The plausible arguments revolve around the hydraulic challenges associated with areas of difficult passage in rivers.

Magnitude: The potential magnitude of hydraulic conditions as a factor is high in under certain conditions, as it could impede recovery, and increase injury, exhaustion and sort times.

Key considerations: Water flow and wave action are products of location. The condition of the fish prior to encounter can potentially influence the ability to recover from the fishing event. High discharge conditions in the Fraser River are already associated with high en route mortality, (Macdonald et al. 2010), therefore, these salmon maybe particularly vulnerable to any additional energetic stress if dip netted or angled in locations of difficult passage or in high water years. Handling gear (e.g., brailer/ramp) and handling time would be key factors related to hydrology.

2.8.6 Predators

Overview of mechanism: Predators can contribute to FRIM as a result of predation on fish that are temporarily impaired while avoiding fish gear, escaping fish gear, trapped in fishing gear (termed depredation), and released after post-capture. These predation events that occur in the context of FRIM are those that would not otherwise occur without the fishing interaction – the predation is additive to natural rates of predation and additive to the rates of FRIM that would occur in the absence of predators. With exception of depredation (predation on fish during the fishing process, before fish are landed), which can be directly observed during some forms of fishing (e.g., Diewert et al. 2002), most of the FRIM associated with predators is cryptic. As such, there is a lack of quantitative information summarized in the available literature to estimate the likely impact of predators on overall FRIM. For instance, particularly in the field, it is very difficult to empirically determine the additive FRIM that is directly caused by predators (e.g., the number of released fish that otherwise would eventually recover and survive but that succumb to predators while temporarily incapacitated after release). This has not stopped some researchers from exploring this potential importance source of mortality. This work is summarized in recent review of post-release predation (PRP) by Raby et al. (2014b). PRP of aquatic organisms (including those that escaped or were intentionally released) occurs when, as a result of a capture event, there are impairment effects on an individual's physiology and/or behaviour that temporarily increases predation risk, typically through a reduced ability to evade predators (although in one study, bonefish released urea and ammonia after capture which attracted predators, lemon sharks [Dallas et al. 2010]).

Studies that have reviewed PRP (n = 28) covered broad taxonomic groups including both fish (n = 22, ~79%) and invertebrates (n = 6, ~21%). Commonly studied fish species included bonefish, red snapper (*Lutjanus campechanus*), sablefish and Walleye pollock. Only one study (Baker & Schindler 2009) considered PRP of Pacific salmonids in their study design, although there are a number of studies that assess physiological, sensory, or behavioural impairments of Pacific salmon after fisheries capture and comment on how these factors could increase PRP (Raby et al. 2014b).

Generally, three different study approaches have been used to assess PRP: studies that infer predation risk by examining behavioural metrics (predator response distance, startle response, schooling, swim speed; e.g., Ryer 2002; Campbell et al. 2009); studies that directly compare predation rates of fish exposed to a simulated capture event versus control fish in laboratory settings (e.g., Ryer 2002; Ryer et al. 2004); and studies that directly estimate predation rates in field (e.g., Ross and Hokenson 1997; Cooke and Philipp 2004). There are also studies that anecdotally observe post-release predation events in field studies, but have no way of providing estimates of the rate of PRP (e.g., Jolley and Irby 1979, Milliken et al. 1999).

Studies on PRP took place mostly in salt water and in both laboratory and field settings. Predation could nevertheless be an issue in some freshwater fisheries (Raby et al. 2014b). For instance, Pacific salmon can be preyed upon by birds, bears, wolves and marine mammals while in fresh water. Most field studies focused on short-term mortality (<~ 24 hr) with few exceptions (e.g., Parsons and Eggleson 2005 and Danylchuk et al. 2007 estimated PRP rates after 24 hrs using observations on less mobile species and acoustic tracking, respectively), and this is partly for logistical reasons but also because post-release predation is most likely to occur in the minutes and hours following release, when the fish is most exhausted and has yet to find refuge.

Estimates of PRP under field conditions, which are the most relevant for fishery management, ranged widely from 6% (Ross and Hokenson 1997) up to 94% (Evans et al. 1994). Surprisingly, short-term estimates of PRP can be extremely high (94%; Evans et al. 1994) and was typically reported in the range of 30-40%. There are few long-term estimates of PRP, which are likely underestimates because sub-lethal effects such as infection can influence an organism over long periods of time. In lab and field studies, factors that increased chances of PRP included fishing-related factors (gear types, air exposure, handling time, capture depth, time on line), intrinsic factors (injury, physiological stress, sensory impairment, reduced predator responses), and extrinsic factors (location - predator densities, season). Despite the potential cumulative effects of temperature and capture stress on PRP, few studies assessed these factors in combination (except see Ross and Hokenson 1997, and Davis and Parker 2004). Moreover, there is very little reporting on depredation in the primary literature for Pacific salmon.

Relevance: In summary, although PRP is commonly acknowledged as a potentially large contributor to fishery-induced mortality, few studies are able to generate accurate and confident estimates of PRP that are useable for fisheries management. One of many difficulties is that predation risk generally increases with decreasing fish size (because of gape limitation of predators), and smaller fish are even more difficult to monitor in the field after release (whether by videography or telemetry tracking). Aside from the effect of fish size, studies have shown that PRP is extremely context specific, varying greatly between species, fishery type, fishery location, and handling practices. On the whole, however, the additive and often cryptic effects of post-release predation will likely remain a major knowledge gap for some time.

Evidence: While there is no uncertainty regarding the direction of the impact that post-release predation or depredation have on fish mortality, there is complete uncertainty in most cases about the frequency and extent of the problem in an additive sense. For instance, predators may often simply be consuming fish that otherwise were destined to die in the absence of predation. In addition, it is very likely that predation risk and post-release predation rates are extremely dynamic (and inconsistent) within a fishery, changing among days and years, depending on the changing abundance and spatial distribution of predators and their usual food sources.

Magnitude: The magnitude of the effect depends strongly on the location and the density of predators. In estuarine areas, for example, the strong presence of seals will greatly impact the likelihood of post-release predation on recreational trolling gear; anecdotal evidence of depredation or post-release predation by seals and sea lions is very common in salmon fisheries in British Columbia, particularly in coastal and estuarine areas.

Key considerations: Certain fishing types are more vulnerable to depredation events, such as gill nets and trolling. The salinity of water will influence the species distribution of the predators (e.g., marine mammals). The size of the fish will limit the type of predator and potentially the selectivity of predator (e.g., target large Chinook). Capture time, and the extent of exhaustion imposed on fish, likely has a large effect on the fish's vulnerability to predators after release. Some of the large studies on depredation were conducted decades ago, when attitudes towards marine mammals were different and population levels of some marine mammals were deliberately suppressed in coastal British Columbia. The increase in abundance of certain marine mammals within coastal waters and their ability to opportunistically use released fish as prey indicates that more work needs to be done to estimate the potential additive contribution to FRIM that predators may have.

2.8.7 Other Factors

There were several other factors that were identified either directly or indirectly through deductive reasoning. These include the following:

- Water Hardness – Salmon recovery from exhaustive exercise is better in hard water (>95 m/L CaCO3) conditions than in soft water (<40 mg/L CaCO3) (Kieffer et al. 2002). This could potentially explain some of the species or population differences seen in release mortality rates.
- Water pH levels – Low pH water reduces the ability of salmon to recover from exhaustive exercise (Ye and Randall 1991). Similarly, future increases in CO2 will likely effect pH and water hardness.

3 FISHING-RELATED INCIDENTAL MORTALITY EVIDENCE CATALOGUE

3.1 INTRODUCTION

The factor analysis review conducted in Chapter 2 focussed on gaining a better understanding of FRIM from a fish-centric perspective. The scope of the factor analysis review included all fish and generated information on key factors to consider when trying to understand FRIM. However, it did not explicitly provide actual estimates of FRIM (i.e., mortality values) for the different types of fishing directed Pacific salmon. Therefore, the next step in the overall study design was to directly connect specific fishing activities to actual estimates of mortality (Figure 1). The knowledge gained in the factor analysis was used in the mortality review to assess study quality and interpret the variability in mortality results across studies.

This mortality review of FRIM for Pacific salmon is designed to evaluate the documented evidence available to inform estimates of mortality that are not related to catch retention. The intent is to provide information to support the derivation of estimates of FRIM rates, which are used in pre-season planning, in-season management, and post-season assessment of Pacific salmon fisheries in British Columbia, Canada. To this end, we have conducted a comprehensive review of the relevant primary and grey literature. The scope of this review includes other anadromous salmonids and fishing methods that are not specific to British Columbia to increase the potential of using the mortality estimate information across Canada. In addition to obtaining estimates of mortality we also extracted information on modifiers (i.e., factors) from each of the studies to better connect the factor analysis with the mortality review (see Figure 1).

3.2 OBJECTIVES

The overall goal of this review is to provide an up-to-date account of the mortality rate information available to inform means of deriving or updating estimates of FRIM for Pacific salmon. To do so, we have created an interactive catalogue of evidence from primary and grey literature using standardized systematic mapping protocols. The structure of the catalogue was designed to accomplish the following key objectives:

- Summarize the extent and distribution of the current evidence base
- Identify the knowledge gaps in the current evidence base
- Provide an overview of the variation in research reliability and relevance
- Generate ideas for potential areas of future research
- Create an up-to-date mortality rate information database

In addition, the design of this evidence catalogue provides a platform to execute a secondary search of the mortality literature, allowing users to target information available for a specified combination of population, intervention, and outcome components.

3.2.1 Design of the Review

We used established systematic mapping protocols in environmental sciences to guide our review of the evidence of FRIM relevant to Pacific salmon (Figure 5). The mapping protocols that we employed herein are best suited to describe the state of knowledge relating to a broad research question (James et al. 2016). And, this comprehensive approach will enhance the repeatability and transparency of our work, as well as establish a means for methodical updates as new knowledge becomes available.

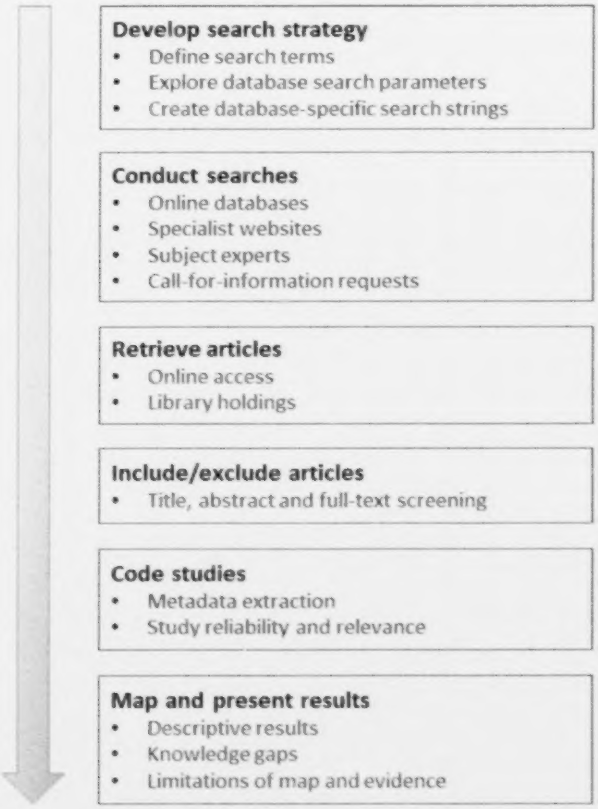
Develop search strategy
• Define search terms
• Explore database search parameters
• Create database-specific search strings
Conduct searches
• Online databases
• Specialist websites
• Subject experts
• Call-for-information requests
Retrieve articles
• Online access
• Library holdings
Include/exclude articles
• Title, abstract and full-text screening
Code studies
• Metadata extraction
• Study reliability and relevance
Map and present results
• Descriptive results
• Knowledge gaps
• Limitations of map and evidence

Figure 5. Overview of the steps in our comprehensive mapping protocol.

Table 2. Descriptions of the components of the mapping question.

Component	Description
Population	Anadromous salmonids
Intervention	Fishery encounter – this includes instances where the encounter is a result of the study fish collection process, thus not necessarily the variable in question

Component	Description
Comparator	(*Not applied in this current mapping question*)
Outcome	Measure of mortality – this includes instances where testing the influence of the intervention on the outcome may not have been the explicit objective

3.2.2 Mapping Question

We initiated our search of the literature with a broad-reaching systematic mapping question to gather the available evidence for FRIM.

What information does the existing literature provide for determining fishery-specific mortality estimates?

The more-specific population, intervention, and outcome components of the mapping question were parameterized to include studies in which the main purpose was not necessarily to assess FRIM (Table 2); some of these studies can provide relevant mortality information while evaluating unrelated research questions. Additional terms that were most relevant to the main application of this review were also imbedded within each search component (Table 3).

3.3 METHODS

Our data collection strategy included searching online databases and organizational websites using documented search strategies. We also sought out additional information from individuals or organizations likely to have information relevant to our question (e.g., academic experts in the field and interest groups engaged in relevant information collection).

3.3.1 Search Terms

We generated the following search terms in consultation with subject area experts who have conducted research on assessing components of FRIM for multiple fisheries.

Table 3. Search terms that were combined with Boolean operators to create search strings specific to individual search restrictions.

Component	Search Terms
Population	"salvelinus", "oncorhynchus", "salmo*", "pink salmon", "pinks", "coho", "chinook", "chum", "sockeye", "steelhead", "trout", "masu", "atlantic salmon"
Intervention	"fishery", "fishing", "fisheries", "netted", "capture*", "catch-and-release", "capture-and-release", "angling", "angled", "gillnet*", "gill net*", "dipnet*", "dip net*", "seine*", "beachseine*", "beach seine*", "purseseine*", "purse seine*", "troll*", "trawl*", "hook*", "tagged", "tag", "holding"
Outcome	"mortality", "mortality rate", "release mortality", "post-release mortality", "postrelease mortality", "post-release survival", "postrelease survival", "survival rate", "discard*", "discard mortality", "fate", "migration success", "died", "death", "depredat*", "drop-out*", "dropout*", "by-catch*", "bycatch*", "drop-off*", "dropoff*"

For online database searches, the terms within each question component were combined using the Boolean operator 'OR'. Components were then combined using the Boolean operator 'AND'.

The effects of wildcards and alternate terms were explored and the search strings were adapted for each database. The database-specific search details are reported in Appendix B (Table B.1 and B.2).

English search terms were used to conduct all searches. In some instances, English abstracts were identified for articles that were written in another language. When this occurred, attempts were made to determine if an English version of the article was available. If so, that article was included in the article screening process.

No document and/or file type restrictions were applied. If books were identified by the search strategy, online PDF copies of the relevant references were manually sought or, when required, hard-copies of the books were obtained. Also, in instances of digital copyright restrictions, hard copies were obtained from DFO libraries.

3.3.2 Searches

Two online databases were comprehensively searched: Thomson Reuters Web of Science and Fisheries and Oceans Canada WAVES online library catalogue (see Appendix B: Table B.1 and Table B.2 for search details). Web of Science is a comprehensive online citation database for multi-disciplinary research that includes journals, books, and conference proceedings. The WAVES database searches the Fisheries and Oceans Canada library collections containing grey literature – published and unpublished government documents – as well as books and journals.

We gathered additional primary and grey literature using several other search strategies. First, we solicited contributions from subject area experts to supplement the electronic searches, and to increase the likelihood that unpublished and grey literature was included and assessed as part of this process. In addition, the websites of organizations known to manage fisheries related to Pacific salmon, or conduct research on FRIM, were explored. Online publication databases of specific organizations were also searched (see Appendix B for details).

Furthermore, in an attempt to collect all sources with the potential to inform FRIM estimates, Fisheries and Oceans Canada Fisheries Management distributed an email request for relevant information. Fisheries Management was responsible for identifying contacts and distributing the call-for-information request. The details of this request can be found in Appendix B.

3.3.3 Inclusion and Exclusion Criteria

Articles identified in the above searches were compiled in MS-Excel. Only those articles compiled from the repeatable searches of the online databases were screened for inclusion in the updateable evidence catalogue. The articles compiled from other sources are available upon request (David Patterson, DFO Science, Burnaby, B.C.).The final subset of relevant articles included in the evidence catalogue met all the population, intervention and outcome inclusion and exclusion criteria defined below.

Inclusion Criteria

Population(s)

- The article provided information on native and/or non-native salmonid species that belong to the *Oncorhynchus*, *Salmo* or *Salvelinus* genera and are fished in Canada.
- The article provided information on marine and/or fresh water fish large enough to be caught in salmon-directed fisheries.

Intervention(s)

- The article provided fish capture information relevant to understanding the impact of salmon-directed fisheries on the above populations of interest.

Outcome(s)

- The article provided information relevant to ascribing mortality to an encounter with a salmon-directed fishery.

Study type(s)

- Reviews were excluded from the catalogue; however, relevant reviews were marked and tabulated for reference (Appendix B).

Exclusion Criteria

Population(s)

- The article only provided information on juvenile fish that are not the target of a salmon-directed fishery.

Outcome(s)

- The article did not provide original empirical information relevant to fishing-related incidental mortality for salmon-directed fisheries.

Study type(s)

- Theoretical articles, model simulations, commentaries and editorials were excluded from the catalogue.

3.3.4 Screening

The titles and abstracts of the articles identified in the online database searches were compiled for review in MS-Excel. The screening of these articles occurred at three levels – title, abstract and full text – using the inclusion and exclusion criteria above. Articles that were excluded at the title or abstract level were coded to document the level of exclusion. This maintained the transparency of the process as well as the integrity of the original search outputs. All articles that were included at the abstract level were then screened at the full-text level. If there was uncertainty about the relevance of an article at the title or abstract level, particularly relevant for those without abstracts, the article was retained for evaluation at the full-text level. The articles excluded at the full-text level and the reasons for their exclusion are listed in Appendix B. The above screening process directly applies to articles found in the Web of Science search; a modified version was applied to the articles found in the WAVES search to expedite the extraction process (see Appendix B for details).

3.3.5 Study Coding

Information was extracted from the final set of included articles using a standardized coding scheme (see details in Appendix B). For articles that presented results from multiple studies, each study was individually coded. The following broad categories of information were extracted:

- Unique reference identifier
- Bibliographic information
- Basic information about study design and location

- Information about populations
- Information about effect modifiers (see below)
- Information about interventions
- Information about mortality estimates
- Information about quality (see section 3.3.6)
- Summary information on the main findings

Our analysis of intrinsic, extrinsic, and fishing factors in Chapter 2 documents the capacity of this information to elucidate mechanisms for variability in mortality results (conceptualized in Figure 2). Thus, information on these modifiers was extracted from each study, where available, to improve our understanding and inform our interpretation of the results. The coding scheme presented in Appendix B provides a list of the effect modifiers considered.

3.3.6 Quality Assessment

Quality assessment information was documented for all included studies. This information was not used as a basis for article inclusion/exclusion during the mapping activities; however, it should be used as an aid in interpreting and extrapolating results from the evidence catalogue when it is being used.

In general, we documented the quality of the information available from each study using two guiding categories: study reliability and study relevance (Collaboration for Environmental Evidence 2013). The former, also referred to as study quality or internal validity, attempts to document the scientific rigour of a study, whereas the latter, also referred to as study utility or external validity, speaks to the generalizability of a study for interpretation given the mapping question.

Information on the following list of study reliability measures was extracted to facilitate the evaluation of a study as it relates to the author's intended purpose:

- Study type
- Sample size
- Replication
- Reference fish
- Statistical method
- Confounding factors (e.g., experimenter effects)
- Effect modifiers

The accessibility of mortality estimates (e.g., direct or indirect extraction due to the style of data presentation) was noted for each study; this information connects the above assessment of scientific rigour to our ability to subsequently interpret the results for our purposes.

Information on the following list of study relevance measures was extracted to provide additional context for the evaluation of a study as it relates to our extraction purposes:

- Objective of study
- Study location
- Study time of year

- Temporal extent of study
- Realism of intervention(s)*

** Note: this measure reflects the type of intervention study; it does not necessarily code whether the intervention is reflective of realistic conditions of an actual fishery, this is to be determined by experts on a specific fishery.*

3.3.7 Method Limitations

The methods used herein to ultimately populate the FRIM evidence catalogue were inclusive of a broad collection of document types; however, this broad scope of inclusion presents a few challenges. For example, the inclusion of various study types (e.g., captive observation, biotelemetry) in the evidence catalogue means caution is needed when interpreting the results of each type and comparing results amongst study types. In addition, language inconsistencies (e.g., definitions, terminology for fishing factors and mortality outcomes) can make interpretation challenging, particularly because we have extracted information across different research niches (e.g., stock assessment, physiology and migration behaviour research). Also, there is a common perception that primary articles are more likely to be published if significant results are presented, thereby leading to an overestimation of effect sizes in any summary review (Haddaway et al. 2016); by combining and comparing primary literature with grey literature, our methods help to address this potential issue of publication bias. However, access to grey literature can be limited due to copyright barriers and, upon retrieval, there is greater potential for extraction of duplicate information already summarized in a primary publication.

3.4 RESULTS

The metadata were compiled from 147 published research articles, 129 from Web of Science and 18 from WAVES (Figure 6). These articles were published between 1959 and 2015 and the vast majority of papers were from primary journals. Thirteen of the studies encompassed multiple experiments that were separated into 162 unique studies, for the purposes of metadata extraction. The final mortality evidence catalogue is available upon request to the lead of author of this document (David Patterson, DFO Science, Burnaby, B.C.) or through the Government of Canada's Open Data Portal (open.canada.ca/open-data). The following is a short summary of the metadata results from the 162 studies that are currently included in the mortality evidence catalogue.

Fisheries assessment was the primary purpose of 129 of the 162 studies. The studies in which the primary purpose was not to evaluate fisheries used fishing intervention as a means to collect sample individuals. Generally, the non-fisheries assessment studies were exploring the migratory behaviour of salmon using seine or angling gear to capture fish for tagging and monitoring. Twenty-three of these 33 studies used telemetry to determine the fate of fish, whereas those studies in which the primary objective was fishing related tended to hold fish for observation (77/129). Seven studies used multiple methods for examining mortality in the same context, generally combining a holding study with a telemetry component. Mark-recapture methodology was the least frequent method used for determining mortality; it was used in eight of the studies extracted.

Population:

Studies were predominantly conducted in North America (Canada: n = 71, USA: n = 68), but the map also extracted from studies conducted in Scandinavia (n = 12), United Kingdom (n = 2), Japan (n = 2), and New Zealand (n = 2). Among the North American studies, 53 were conducted in British Columbia and focused on migratory Pacific salmonids. Within British

Columbia, most of the studies have taken place in the Fraser River (n = 31) or South Coast in general (n = 47) with only eight in central of North Coast Area including Skeena.

The metadata reports on salmonid fishes, including all migratory Pacific salmonids as well as Atlantic salmon (both anadromous and landlocked) and freshwater salmonids such as charr, brown trout (*Salmo trutta*) and cutthroat trout. Mortality data were frequently extracted from papers addressing freshwater salmonids (n = 40) which included lake trout (*Salvelinus namaycush*), brook trout, resident rainbow trout and cutthroat trout, and brown trout. Data from Atlantic salmon studies were the next most frequently extracted, addressed in 30 of the extracted studies. Coho (n = 36), Chinook (n = 35) and sockeye (n = 33) were the most commonly addressed migratory Pacific salmon, with limited information on chum or pink salmon (see Raby et al. 2013 for exception). We did not find any estimates of mortality for Arctic charr (*Salvelinus alpinus*).

Overall, studies were predominantly conducted in the freshwater environment (n = 119); this was particularly predominant outside of North America where all but one study was conducted in fresh water. This corresponds with the observation that most studies were focused on calculating mortality of resident freshwater salmonids. Studies in the marine environment (n = 47) were mostly conducted on coho (n = 24) and Chinook (n = 18).

Intervention:

The interventions reflect the dominant fisheries sectors for each group of species. For example, most freshwater salmonids (23/39) and Atlantic salmon (15/30) studies focused on recreational angling, whereas Chinook, sockeye, and coho salmon were studied in the context of both recreational and commercial fisheries. Mortality was most frequently characterized for all salmonids released by recreational angling (n = 72). Angling interventions included fishing with recreational trolling, spinning or fly fishing gear. Although angling was conducted in the marine environment (n = 14), studies focused on angling in fresh water (i.e., lakes, rivers or streams; n = 62); four studies evaluated angling in both environments. Seine (beach: n = 18, purse: n = 11) gear was the next most common fishing gear type evaluated in the studies followed by variants of gill nets (gill net: n = 24; tangle net: n = 10). Several studies had non-fishery interventions such as removing fish from fish wheels (e.g., Cook et al. 2014), trap nets (e.g., Lennox et al. 2015) or electrofishing (e.g., Bouck and Ball 1966). Other studies removed fish from fishways or hatchery tanks using dip nets; depending on the context of the capture, these interventions may have been conducted to generate control or reference values of mortality for comparison with fish captured by other methods. However, studies that used these other interventions were mostly conducted for purposes other than evaluating fishing mortality (17/27), attempting to capture fish without causing substantial stress. Twelve studies used simulated fishery interventions to induce exhaustion (e.g., Kieffer et al. 2002) or injury (e.g., Kojima et al. 2004), particularly on hatchery fish or in laboratory settings.

Mortality outcome:

Only twelve studies reported on drop-off mortality, and most were simply related to reports on depredation. Fourteen studies only quantified immediate mortality of fish landed (e.g., Gutowsky et al. 2011). Studies tended to either evaluate short-term mortality (immediate or 0-24 hr: n = 71) or long-term mortality (terminal or > 96 hr: n = 85). Telemetry studies tended to focus on longer-term intervals: 82% of the mortality estimates presented for mortality studies were long-term estimates. Holding studies were predominantly conducted to calculate 24 h mortality (n = 41), but there were also long-term (> 96 hr) holding studies (n = 33). Fifteen papers reported mortality estimate to the terminal areas.

Mortality estimates were extracted from the 162 studies, representing over 1000 empirical mortality estimates. The sample size from which mortality estimates were derived ranged from one to 72,698 fish, the latter in Schill et al. (1986). Mortality estimates were highly variable as a function of the sample size and intervention as well as the conditions specific to each study. These estimates ranged from 0% to 100% mortality.

Fishing factors:

Gear types used for capturing fish were predominantly reported for studies with angling or trolling gear but occasionally for netting studies (e.g., mesh type, hole diameter). Comparisons among gear types are particularly salient for angling studies because of the vast diversity in methods used for fish capture, including size, number, and shape of the hook as well as the type of bait or lure used to attract the fish. Regulating the gear types available for fishers can contribute to fish conservation if there are significant differences in the condition of fish captured by different gear types. Eighty-six studies reported some detail of the capture gear used in the study, among which 52 were angling studies. Overall, 22 of 31 studies that tested gear effects found they were a significant contributor to post-release mortality, reinforcing the importance of selecting appropriate gear for the fishing event in order to mitigate post-release mortality.

Twenty studies in this review employed some form of revival technique but only one of the three studies that tested the technique identified a significant increase in survival of revived fish; Farrell et al. (2001b) showed that seemingly moribund coho salmon captured by commercial gill net in the marine environment had higher survival when placed in a revival box. Commercial fishing operations have implemented this tool to revive fish captured as non-target prior to releasing them. In recreational fisheries, however, Robinson et al. (2015) found limited evidence to support the use of fish revival techniques.

Fifty-one of the studies reported on capture time, the meaning of which varied by intervention from soak time (gill-netting studies) to fight time (angling studies) or exercise time (simulations involving manual exercise or swim flumes). However, capture time was significant in five of 15 studies that tested whether it influenced post-release mortality, with longer soaks of beach seine (Candy et al. 1996) and gill net (Buchanan et al. 2002) increasing post-release mortality. There is certainly more opportunity to identify better thresholds for soaks times in commercial fisheries to identify durations that can promote recovery and survival of non-target fish. In recreational fisheries, it is not surprising that capture duration was not significant in all five of the studies for which it was tested, but capture duration would probably be relevant when considered as an interaction with water temperature, air exposure duration or fish size.

Handling and especially air exposure can exacerbate these responses and may have a significant impact on the probability of mortality in fisheries (Cook et al. 2015). Handling can remove scales or mucus, causing bruising when fish are dropped, and damage fins or the operculum. Although we intended to extract handling technique data relevant to the use of nets for landing fish or pliers for removing hooks, we also extracted data on handling techniques that included scientific handling details such as whether fish were anaesthetized for tagging. Three studies found significant increases in mortality of critically hooked salmonids from which the hook was removed compared to those from which the line was cut. Handling techniques often require air exposure as fish are disentangled from nets or removed from hooks. In spite of the significant contribution air exposure makes to a fisheries interaction, few studies (13/162) reported fish air exposure times. Moreover, only four studies analyzed air exposure as a possible predictor of post-release mortality, three of which found that it was not a significant predictor. For example, Nguyen et al. (2014) compared survival of sockeye captured in beach seines and air exposed for zero or two minutes before release and found no difference in survival to spawning grounds (55% and 59%, respectively), but they could not isolate air exposure from other capture-stressors. Water temperature is understood to have a strong interaction with air exposure duration (Gingerich et al. 2007) but studies did not generally consider the interaction.

Extrinsic factors:

Water temperature is established as an important factor that contributes to poor condition of captured fish (Gale et al. 2013). Correspondingly, most of the studies (n = 97) reported, tested, or considered water temperature. However, many of these studies only reported water temperatures that were recorded upon capture, often as a range of temperatures or simply the mean temperature logged at the surface over a period of several days or weeks during which fish were sampled. Eleven studies incorporated temperature in some sort of statistical test to determine whether the mortality of released fish was associated with the capture temperature. Mean temperature and temperature ranges indicated that most of the results were from salmon captured at moderate water temperatures (10-19°C). Cold water is better oxygenated than warm water, probably contributing to the preference for cool water by salmonids. Oxygen demands determine the niche breadth of many salmonids, particularly in lakes, and can also have fisheries consequences. However, only four of the studies in this review reported dissolved oxygen in their study systems. None of these studies analyzed the influence of dissolved oxygen on survival, possibly because it is difficult to measure the oxygen experience of the fish (e.g., the dissolved oxygen logged at a single location such as the surface layer may not reflect the experience of the fish).

Salmonids are considered to be cool-water species and may behaviourally thermoregulate in rivers (e.g., Goniea et al. 2006) or use deep layers of lakes to maintain homeostasis (e.g., Mathes et al. 2010). Thus, salmonids are sometimes captured at considerable depth and brought to the surface. This can cause barotrauma by which the rapid ascent through the water column causes internal damage in salmonids (Brown et al. 2009). None of the studies discussed instances of barotrauma among captured fish; however, 17 reported or considered the capture depth. None of the studies tested whether capture at different depths influenced mortality and thus, no significant effect of captured depth was reported.

Water chemistry could influence the physiological response to exhaustive exercise, recovery from exercise, and mortality, but it was generally not reported. However, both Graham et al. (1982) and Kieffer et al. (2002) tested for the effects of water chemistry on the survival of exercised salmonids. Both studies identified a significant effect of water acidity and hardness on mortality, generally identifying high mortality of exercised salmonids in soft water.

Intrinsic factors:

Fish size was commonly provided in the studies (n = 98), generally as a range or mean value; it was tested as a possible contributor to mortality in 17 studies. However, the direction of the relationship between mortality and fish size was inconsistent, probably because it depends on a variety of factors, such as hook size. The sex of fish is also potentially relevant to post-release mortality, yet very few studies considered the effect of sex on mortality. Sex is not often considered by analysts (Hanson et al. 2008), probably in part because salmonids are sexually monomorphic except during the final stages of maturation among migratory populations. Yet, among the six studies that tested whether sex influenced mortality, only two identified a significant effect; female salmon tended to have higher post-release mortality than males (Keefer et al. 2010 and Robinson et al. 2015).

Fish condition can be approximated by the injury status upon landing in fishing gear. Injuries such as bleeding, fin fraying, scale loss, mucus loss, or internal damage to organs can significantly affect the probability of surviving a capture event, particularly for migratory fish that are not feeding and must recruit energy from fixed somatic reserves to heal wounds and fight infection. Pre-existing conditions such as injury or disease are relevant to fisheries such that fish that are in poor condition and then captured by fisheries would be less likely to survive. Disease can be inferred from gene expression data to evaluate the extent to which a fish is burdened by pathogens and disease (Miller et al. 2011). However, none of the studies in our review attempted to relate disease status of captured fish to their survival. Pre-capture injury is easier to assess but it is generally difficult to ascribe injuries of captured fish to the present capture event or to less proximate stressors, and it follows that few of the studies that we reviewed provided an assessment of the pre-capture condition. An exception, Keefer et al. (2010), captured Chinook salmon in a fish trap and found that fish in poor condition tended to have lower survival than fish in good condition upon capture. Injuries can also be incurred when fish are physically damaged by hooks or netting. Capture injury was frequently reported in the studies (n = 50), often as hook location or bleeding, and tested as a potential contributor to post-release mortality in 20 of the studies. When tested, capture injury was a significant predictor of post-release mortality in 17 of those 20 studies. Physical injuries caused by hook damage, particularly when the hook penetrates organs (e.g., gill arches, esophagus, stomach) or vascularized areas of the mouth (e.g., tongue), are considered to be one of the most relevant predictors of post-release mortality in fish (Muoneke and Childress 1994). In some Atlantic salmon fisheries, local guidelines stipulate that anglers not release fish that are hooked in such critical locations due to fish welfare concerns (Lennox et al. 2015). One important piece of information that is not well established, however, is whether there is an interaction between hooking injury and water temperature. Although both temperature and injury were frequently addressed, they were not explored as potentially interacting effects.

Study quality:

There are strengths and weaknesses to the different methods used to estimate FRIM (Raby et al. 2015b). Mortality of fresh water salmonids was generally determined using holding studies (n = 30), whereas telemetry was more frequently implemented for Atlantic salmon (16/32), sockeye (19/33), and steelhead (7/11). Interestingly, coho (23/36) and Chinook (17/35) tend to be evaluated in holding studies. Seven studies used multiple methods to determine FRIM. There were two studies that compared the mortality estimate derived from holding and telemetry (Donaldson et al. 2011 and Raby et al. 2015c).

Fisheries mortality is ideally contrasted to natural mortality in order to calculate the additional mortality attributable to fishing. Natural mortality is highly variable among species, populations, and systems; it is extremely difficult to calculate because it is necessary to capture and manipulate fish to quantify mortality, contravening the intention of calculating natural mortality. Studies in our review used a variety of approaches to generate baseline, reference, or control values of mortality, often by capturing fish by a different method than the intervention being assessed. The alternative capture methods were mostly electrofishing or trap netting but also occasionally included beach seines. Most of the studies captured control fish to separate the handling and tagging mortality from the fishing mortality; however, one study used an untagged control group in a holding pen to separate tagging effects from fishing mortality (English et al. 2005). Another study used a control group that was captured but not handled (i.e., held at different water temperatures) to separate fishing and tagging from the handling effects (Crossin et al. 2008). One study used alternative approaches to separate fishing mortality from handling or tagging mortality without the use of a control group per se. In Raby et al. (2014a), for example, reflex action mortality predictors (RAMP) were used to separate normal impairment associated with handling stress from high impairment associated with fishing-related stressors that were predictive of post-release coho salmon mortality. Overall, only 36 of the 162 studies provided mortality estimates for a control or reference group, and fishing control mortality tended to be very low (0.00-0.05).

An important shortcoming of many of the studies was the failure to make appropriate statistical inferences on the data. Eighty-one of the 162 studies implemented no statistical analysis to model mortality. Studies that did not use any statistical analysis may have done so due to small sample size (e.g., Whoriskey et al. 2000) precluding proper model fits. Additionally, there were studies from which we extracted mortality data that was not provided for this intent but reported as a note in the methods or results. For example, among 33 studies for which the primary purpose was not related to fisheries, approximately half did not provide any analysis of mortality, likely because such an analysis was peripheral to the study aims. Twice as many studies provided univariable analyses of mortality, generally chi-squared tests or Fisher's exact tests, to ascribe significance of single predictor variables to mortality. Univariable approaches are simple and effective for testing specific hypotheses in controlled settings where there is unlikely to be significant influence of external variables. In real capture fisheries, however, fish are exposed to fluctuating conditions of temperature and salinity and there is considerable variation in fish size, sex, maturity, disease, and other factors that can contribute to mortality or have synergistic interactions with other variables of interest such as hooking injury or capture time. Yet, only 21 of the 162 studies implemented multivariable approaches to test the main effects on mortality, similar results were found by Johnson et al. (2012).

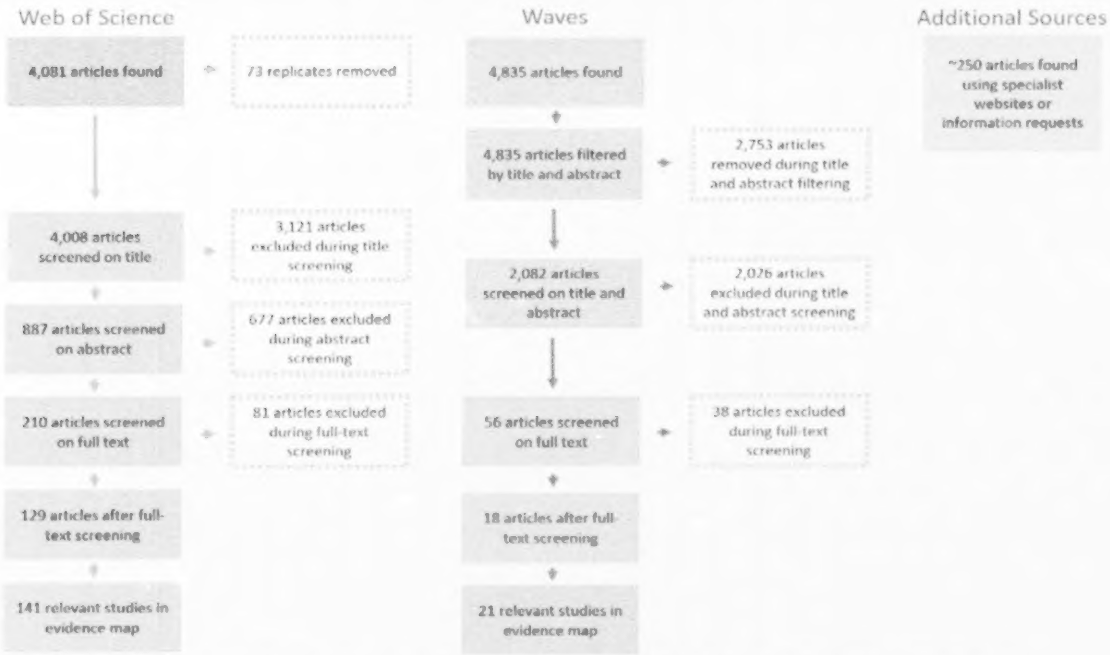
Web of Science
Waves
Additional Sources
4,081 articles found
73 replicates removed
4,835 articles found
~250 articles found using specialist websites or information requests
4,835 articles filtered by title and abstract
2,753 articles removed during title and abstract filtering
4,008 articles screened on title
3,121 articles excluded during title screening
2,082 articles screened on title and abstract
2,026 articles excluded during title and abstract screening
887 articles screened on abstract
677 articles excluded during abstract screening
210 articles screened on full text
81 articles excluded during full-text screening
56 articles screened on full text
38 articles excluded during full-text screening
129 articles after full-text screening
18 articles after full-text screening
141 relevant studies in evidence map
21 relevant studies in evidence map

Figure 6. Flow diagram of mapping stages for articles found in the online database searches. The potential overlap in articles from different search methods has not been accounted for in the numbers presented here. The full-text exclusion of articles was the result of the inclusion/exclusion criteria (section 3.3.3; Appendix B) as well as problems with article retrieval (Appendix B3 and B5). The final remaining 147 articles were expanded to individual study resolution to generate 162 study extractions in the comprehensive map output for both Web of Science and WAVES. The number of articles found using specialist web sites, expert contacts and call-for-information request search strategies are also presented. The details for these search returns as well as the relevant WAVES articles are available upon request (David Patterson, DFO Science, Simon Fraser University, Burnaby, BC, personal communication, 2016).

3.5 CONCLUSIONS AND APPLICATIONS

The interactive evidence catalogue documents the existing primary and grey literature base for understanding FRIM for anadromous salmonids in Canada. It can be used as an information guide by various interest groups as well as a platform to acknowledge information gaps and provide focus for future research efforts. Because of the methodical approach used to address our broad-reaching mapping question, the database can be updated with future information.

The factor analysis in Chapter 2 provides a detailed assessment of the current knowledge base available to aid in our understanding of how intrinsic, extrinsic, and fishing-related factors can influence the mortality of fish encountering a fishery. This understanding enhances our interpretation of the mortality results in the evidence catalogue and helps to extend the functionality of the database. The following list summarizes the main outputs of this chapter:

- Searchable and updatable database of mortality evidence for anadromous salmonids
- Systematic process in place to extract mortality estimates from the literature, including an approach for evaluating and documenting study reliability and relevance
- Mortality evidence and associated metadata to be used in scaling key risk factors for incremental risk of mortality (Chapter 4)

4 FISHING-RELATED INCIDENTAL MORTALITY SYNTHESIS

The factor analysis presented in Chapter 2 identifies and summarizes the available literature relevant to understanding factors that can influence FRIM. The mortality evidence catalogue described in Chapter 3 presents literature-based mortality values that further our understanding of mortality risk given the context of a fishery encounter relevant to anadromous salmonids in Canada. In this chapter, we synthesize this information in a manner that is useful for describing and predicting FRIM under different fishing conditions. We introduce a process for generating key risk factors that we propose can be used to explain a large portion of the variance in FRIM values for Pacific salmon. The risk factors are then scaled against the incremental risk of mortality using information from the factor analysis, mortality evidence catalogue, and subject-area experts. This scaling provides a risk score for individual risk factors that can then be combined and used in a risk assessment of FRIM across different fisheries (see Patterson et al. 2017).

4.1 RISK FACTOR SELECTION

Chapter 2 provides a considerable volume of research that examines factors relevant to FRIM. In order to distill this information, we have summarized the evidence and applied judgement to assess the utility of each factor. For the latter, the authors responsible for generating factor-specific summaries for Chapter 2 were surveyed to provide informed feedback on the evidence base and operationalization of the factors with respect to FRIM. Overall, the risk factor selection process was informed by two main outputs:

1. A review of the amount and consistency of evidence for each factor and the biological mechanism that links the factor to mortality (Table 4)
2. A review of the utility of each factor based on the magnitude of the effect it has and on the ability to scale it against a risk of mortality (Table 5)

The following list provides more detail on the key features of the first output (Table 4).

- *Amount of evidence* – A summary of the amount of evidence for fish (excluding salmonids) and salmonids, for each factor, was compiled. The amount of available evidence was coded as 'high' indicating greater than 30 primary sources, 'medium' indicating 10 to 30 primary sources, or 'low' indicating less than 10 primary sources. A total of 384 primary sources were used from the factor analysis repository (see section 2.2). The more evidence of a given factor impacting FRIM, the more scientifically defensible the factor would be as a potential risk factor.

- *Consistency of the evidence* – The evaluation of consistency was accomplished by reviewing the primary literature for salmonids and incorporating expert judgement from the authors. We converted the resulting information into the following categories: 'consistent' which refers to a factor with evidence of a predictable and directional response in nearly all situations; 'variable' which refers to a factor with evidence of a predictable response but the direction of response varies depending on the specific context, and therefore it is not applicable to all fishery situations; 'inconsistent' which refers to a factor in which the evidence presents an opposing response in seemingly similar conditions; and 'data deficient' which means that the evidence compiled was not enough to categorize the response. We recommend that only factors identified as consistent or variable should be considered as potential risk factors.
- *Biological mechanism* – Experts were asked to provide evidence of the biological mechanism that links the factor to mortality via the fish response. For consideration as a risk factor, there had to be clear physiological or injury response linked to acute and/or latent mortality; predators were an exception given there is a direct link to fish mortality.

There are numerous factors identified that could be used as potential risk factors to describe FRIM (Table 4). However, not all factors are equal in their usefulness in terms of describing or predicting FRIM for anadromous salmonids. As such, the second step was developed to articulate aspects of each factor that support either the inclusion or exclusion of a given factor as being a potential risk factor. The following list identifies the key utility features presented in the second output (Table 5) that was used to inform the selection of risk factors.

- *Scalability* – Experts were asked to comment on the ability to scale the factor against the risk of mortality, either as a continuous variable (e.g., water temperature) or a binary response (e.g., hook type). The responses were coded as 'yes' indicating the factor is easy to scale, 'hard' indicating the factor is difficult to scale but not impossible, 'no' indicating that the ability to scale the factor is unlikely at this time, and 'RAR' (i.e., Risk Assessment Required) indicating the impact of a given factor could be determined by assessing the other underlying risk factors in an separate risk assessment. The 'RAR' code applies to fishing method variation because the potential for variability in fish response as it relates to fishing method is mediated via other more generic factors (e.g., capture time, handling time). At this time, we only considered factors that were coded as *yes* to be suitable for consideration as a potential risk factor.
- *Magnitude of effect* – Experts were asked to comment on the likely magnitude of impact a given factor would have on drop-off mortality or release mortality. Direct scientific support and indirect evidence were used to evaluate the potential role of each factor in FRIM. The responses were mostly subjective; they were coded as 'high' which denotes a large effect, 'medium' which denotes a moderate effect, 'low' which denotes a small effect, and 'none' which denotes a lack of effect. Those factors with *low* or *none* codes were excluded from further consideration as a risk factor. We defaulted to the higher value in cases of inconsistency among experts, if clear evidence was provided.
- *Considerations* – For each factor, experts were asked to comment on the limitations and considerations of using the factor in predicting FRIM. Limitations refer to specific challenges in either determining the impact scale of a factor or in assessing the factor in real fisheries.

We evaluated further considerations to determine whether the mortality risk associated with this specific factor could be reflected via a surrogate risk factor(s) that might be easier and more practical to score, or be more indicative of the underlying biological processes associated with the fish-centric approach to FRIM. In many cases, several alternate methods of scoring the associated risk of a specific factor were determined. The generation of suitable proxies would reduce the number of risk factors, as well as reflect some of the mortality risk associated with factors that are important but cannot be readily scaled. It has already been established that there is a mechanism or pathway(s) for connecting a given factor to a specific fish response (i.e., stress, injury, infection, behaviour) that can ultimately lead to mortality. If the risk of a specific factor can be represented by a surrogate factor (i.e., proxy) that better reflects the underlying fish response and mortality, then we feel the process is more scientifically defensible and more robust to future changes in fishing methods or gears. For example, the mortality risk associated with variations in gear types are normally reflected in variations in the severity of injury they cause, so by focusing on injury, we can be more direct and reduce the number of risk factors required.

Table 4. This table presents an overview of the amount and consistency of evidence for the relationship between a factor and fishing-related incidental mortality (FRIM). The amount of evidence in the primary literature is presented using three categories: 'high' indicates that evidence was compiled from more than 30 sources, 'medium' 10 to 30 sources, and 'low' < 10 sources. A total of 384 primary sources were evaluated. The consistency of evidence results are presented using four categories: 'consistent' refers to a factor with evidence of a predictable and clear directional response in nearly all situations, 'variable' refers to a factor with a predictable response but the direction of response varies depending on the specific context, 'inconsistent' refers to a factor in which the evidence presents an opposing responses (i.e., unpredictable) in seemingly similar conditions, and 'data deficient' means that the evidence compiled was not enough to categorize the response. An asterisk in the consistency column alters the interpretation of 'consistent' to represent a broad factor with consistent evidence of its importance in understanding mortality. An 'X' in the respective 'fish response' columns presents the likely biological mechanism(s) that links a factor to mortality.

Factor Category	Factor	Amount of Evidence		Consistency of Evidence	Fish Response			
		Fish	Salmonids	Salmonids	Stress	Injury	Behaviour	Infection
General	Capture Time	High	High	Consistent	X	X	X	-
General	Handling Time	High	High	Consistent	X	X	X	-
General	Handling Technique	Medium	Medium	Consistent	X	X	X	X
General	Air Exposure	High	Medium	Consistent	X	-	X	-
General	Revival Technique	High	Medium	Inconsistent	X	-	X	-
Net/Trap	Catch Size	Medium	Low	Variable	X	X	-	-
Net/Trap	Crowding	Medium	Low	Consistent	X	X	X	-
Net/Trap	Confinement	Medium	Low	Consistent	X	X	X	-
Net/Trap	Catch Composition	Medium	Low	Consistent	X	X	-	-
Net/Trap	Mesh Size	Low	Low	Variable	X	X	-	X
Net/Trap	Mesh Type	Low	Low	Inconsistent	X	X	-	-
Net/Trap	Method Variation	High	High	Consistent*	X	X	X	X
Hook/Line	Bait vs. Lure	High	Medium	Consistent	-	X	-	-
Hook/Line	Hook Type	High	High	Consistent	X	X	-	-
Hook/Line	Hook Size	High	High	Consistent	X	X	-	-
Hook/Line	Hook Location	High	High	Consistent	X	X	-	-
Hook/Line	Handling Gear	Medium	Low	Variable	X	X	X	X
Hook/Line	Method Variation	High	Medium	Consistent*	X	X	X	X
Intrinsic	Physiological Condition	High	High	Variable	X	-	X	X
Intrinsic	Size	High	High	Variable	-	X	-	-
Intrinsic	Species	Medium	Low	Variable	X	X	X	-
Intrinsic	Maturity	Low	Low	Variable	X	X	X	X
Intrinsic	Sex	Low	Low	Consistent	X	-	X	-
Intrinsic	Pre-capture Injury and Infection	Low	Low	Consistent	X	X	X	X

Factor Category	Factor	Amount of Evidence		Consistency of Evidence	Fish Response			
		Fish	Salmonids	Salmonids	Stress	Injury	Behaviour	Infection
Extrinsic	Water Temperature	High	High	Consistent	X	-	X	X
Extrinsic	Dissolved Oxygen	Medium	Medium	Consistent	X	-	X	-
Extrinsic	Suspended Sediment	Low	Low	Consistent	X	X	X	-
Extrinsic	Salinity	Medium	Low	Inconsistent	X	-	-	-
Extrinsic	Hydrology	Low	Low	Data Deficient	X	X	X	-
Extrinsic	Predators	Low	Low	Consistent	X	X	X	X

Table 5. This table reviews the potential utility of each factor as it relates to the ability to scale the incremental risk of mortality against the severity of the factor experience for drop-off and release mortality. The ability to scale a factor is denoted using four categories: 'yes' indicates the factor is easy to scale, 'hard' indicates the factor is difficult to scale but that it is possible, 'no' indicates that the ability to scale the factor is unlikely at this time, and 'RAR' indicates a risk assessment of other factors would be required. The likely magnitude of effect that a factor may have on each of the two mortality components is presented using four qualitative categories: 'high' denotes a large effect, 'medium' denotes a moderate effect, 'low' denotes a small effect, and 'none' denotes a lack of effect on mortality. The table also include practical limitations of use, and considerations (i.e., major issues to consider or alternative methods of scaling the impact) for each of the factors in relation to their potential use as a risk factor.

Category	Factor	Scale	Drop-off	Release	Limitations and Considerations
General	Capture Time	Yes	High	High	variation in severity of stress response by gear types can influence scaling; impact of stress scaled by duration and type of fishing
General	Handling Time	Yes	None	High	may be hard to standardize and quantify given the variation how fish are handled (i.e., in air vs. in water); handling stress scaled by duration of the type of handling
General	Handling Technique	Hard	Low	Medium	too subjective or difficult to quantify and assess; impact reflected in capture/handling times and injury
General	Air Exposure	Yes	None	High	some challenge for species and location differences; potential modifiers to response (species, size, age, previous exercise, condition); severity expressed by duration
General	Revival Technique	Hard	None	Low	difficult to quantify effectiveness given it can both mitigate (i.e., poor condition fish) and exacerbate (i.e., vigorous fish) stress response; impact reflected in handling time
Net/Trap	Catch Size	Yes	Medium	High	too variable a response (e.g., may be irrelevant for injury if no crowding occurs; density maybe more relevant); impact reflected in handling times and injuries
Net/Trap	Crowding	Hard	None	Medium	difficult to quantify/measure density; reflect impact through handling time, injury, temperature
Net/Trap	Confinement	Hard	None	Medium	difficult to quantify/measure; reflect impact through capture time
Net/Trap	Catch Composition	Hard	None	Low	difficult to estimate due high variable, some will have large impact (e.g., spiny fish can lead to injury/wounds); impact reflected in species, handling and injury
Net/Trap	Mesh Size	Yes	High	High	too variable a response given interaction of fish size to mesh size ratios; impact reflected in fish size, injury and temperature
Net/Trap	Mesh Type	No	Unknown	Medium	inconsistent information to date; impact reflected in injury
Net/Trap	Method Variation	RAR	High	High	limited comparative studies to make gear comparisons directly; impact reflected in injury, water temperature, capture time, handling time
Hook/Line	Bait vs. Lure	Yes	Low	Medium	difficult to assess; impact through hook location, injury and handling time
Hook/Line	Hook Type	Yes	Unknown	Medium	difficult to regulate or assess, impact modified through hook location, injury and handling time

Category	Factor	Scale	Drop-off	Release	Limitations and Considerations
Hook/Line	Hook Size	Yes	Low	Low	difficult to regulate or assess; impact modified through hook location, injury, fish size and handling time
Hook/Line	Hook Location	Yes	Low	High	difficult to assess or generalise; impact reflected in injury and handling times
Hook/Line	Handling Gear	Yes	None	Low	highly variable response; impact reflected in injury
Hook/Line	Method Variation	RAR	High	High	limited direct comparative studies on Pacific salmon; impact reflected through injury, capture times, handling times, and predation
Intrinsic	Physiological Condition	Hard	Medium	Medium	not a reliable predictor of mortality; can only be used to understand mechanisms and explain mortality patterns,
Intrinsic	Size	Yes	Medium	Medium	survival predictions are variable depending on many factors (e.g., gear type, temperature), impact reflected in injury, capture time, and handling.
Intrinsic	Species	Yes	Medium	Medium	effects inconsistent and limited comparative studies and difficult to control for other key factors; future potential to reflect impacts
Intrinsic	Maturity	Hard	Low	Medium	difficult to quantify, species dependent; impact reflected in injury
Intrinsic	Sex	Yes	Low	Medium	impractical to use sex can't be identified where the bulk of fish capture occurs (marine and early river entry)
Intrinsic	Injury & Infection	Hard	Medium	Medium	too difficult to assess pre-capture injury and infection in a real fishery
Extrinsic	Water Temperature	Yes	High	High	species or population differences, and natural mortality are challenge; risk cannot be reflected in another factor
Extrinsic	Oxygen	Yes	Low	Medium	dissolved oxygen is variable and too dynamic to be measured consistently; not possible to reflect risk at this time
Extrinsic	Suspended Sediment	Yes	Low	Low	limited occurrences and impractical difficult to measure in a fishery; impact reflected in injury
Extrinsic	Salinity	Yes	Low	Low	very difficult study designs to make comparisons due to other factors (feeding, maturation, temperature predators) independent of salinity; not possible at this time to reflect risk
Extrinsic	Hydrology	No	Low	Low	impractical to quantify; impact reflected in injury or capture time
Extrinsic	Predators	Yes	Medium	Medium	difficult to quantify abundance or impact but still highly relevant given the direct mortality response; risk of habituated predators cannot be reflected in a different factor

We retained all factors during the evidence and utility review process. It should be repeated that the information presented is a combination of information from the literature and informed judgement. The relative proportion of the contributions of these information sources varies for each factor, but we propose that the benefits of presenting these table summaries (i.e., promote dialogue and highlight areas of knowledge gaps) outweighs some of the subjectivity presented. We have strived to produce transparent outputs to allow for future additions to these tables as more research is conducted.

The analysis of the magnitude and utility of each factor highlighted a limited number of factors that could actually be scaled against the risk of mortality without any major limitations (Table 5). Further analysis of the consideration comments indicated that the mortality risk associated with all of the factors could be reflected in a select number of fish response pathways that connect each factor to a mortality risk. We focused our selection on these common pathways to arrive at our main risk factors. The factor selection process resulted in five proxies for assessing the risk of mortality associated with a fishery encounter. The mortality risk associated with all of the factors listed in Table 5 could be reflected to varying degrees by scoring the risk associated with the following risk factors – capture, handling, injury, water temperature, and predators (e.g., handling time would reflect the exhaustive stress associated with crowding). Conversely, the mortality risk associated with these five risk factors could not be reflected by scaling a different factor (e.g., there is no suitable proxy for air exposure). These five factors all represent core features linking fishing activities and the environment to fish response and mortality risk. Meaning, the overarching process for selecting the specific combination of risk factors was grounded in our understanding of a fish response to a fishery encounter. We aimed to ensure that the main aspects of a fish response that can lead to acute or latent mortality were reflected by the selected risk factors.

The capture risk factor is designed to reflect the stress that starts at the initiation of the fishing encounter and continues until capture (i.e., when the fish is under control of the fishery). The mortality risk associated with capture is affected by the magnitude of the acute physiological response to the gear encounter and the severity of the stress and reflex impairments associated with exhaustive exercise. The criteria used to scale the mortality risk of capture stress is a function of the overall duration of the different types of capture stressors (e.g., exhaustive exercise, physical restraint, confinement) associated with different types of fishing. Handling stress begins immediately after capture and ends at release. The handling risk factor is designed to reflect the acute and chronic stress associated with removing fish from gear, and sorting and handling fish, including any intervening air exposure or attempts at revival. Therefore, the criteria used to score handling is a composite of the two major stressors associated with a handling event, namely the duration of handling in air and the duration of physical contact with gear, humans, or other fish in water. In this manner, handling can be used to incorporate some of the risk posed by other fishing factors that were not selected for direct use (e.g., crowding). The injury risk factor reflects the physical damage to fish caused at any point during the encounter with the numerous factors associated with fishing operations. Also, injury was selected to integrate the injury component associated with the different fishing factors (e.g., gear types). Injury is pervasive to all fishery encounters, the exception being those fish that avoid the gear, and so the injury scaling is devised to reflect the mortality risk of all fishing factors that can influence injury based on the type of injury that can result. The water temperature risk factor was included to reflect the incremental mortality associated with acute and latent stress responses that occur at high temperatures (e.g., more severe stress response during capture, inability to recover from exhaustive exercise) and the increased risk of infection that occurs with increasing temperature. Water temperature is the main environmental factor that we are currently able to scale against a risk of mortality in all fisheries. The added mortality risk associated with water temperature cannot be reflected in any other risk factor, likely because of the central role that water temperature has in regulating many aspects of the stress response, recovery from exercise, and development of infectious disease (exacerbated by injury and chronic stress) in salmon. We have considered capture, handling, injury, and water temperature as generic risk factors, as they are likely to combine and contribute to an overall mortality estimate.

The mortality risk that habituated predators or predators in high abundances can have on both drop-off and release mortality cannot be accurately reflected in another risk factor; the risk is context specific, meaning the mortality risk associated with predators is only relevant to certain situations. The predator risk factor was included to represent the direct impact that abnormally high levels of predation can have on FRIM. We felt that the limitations associated with observing cryptic predation events were compensated for by the lack of ambiguity over the mechanism by which the factor clearly elevates the mortality risk. We propose that other context-specific factors could be added to the list with further research, including potential mitigating factors such as the use of revival methods. The current five risk factors selected, four generic and one context-specific, represent the current state of knowledge on FRIM.

4.2 MORTALITY RISK FACTOR SCORING

The next step in synthesizing the information involved scaling each of the risk factors against the risk of mortality. Information used to scale these factors came from the empirical studies cited in the factor analysis (sections 2.3 to 2.8), recent unpublished data, judgment by the authors with subject area expertise, and extracted mortality estimates from the mortality evidence catalogue (section 3.4). Information is not available on all combinations of factors, species, and major fishing types, so inferences with respect to scaling the impact levels were made across fishing types and species. For example, the majority of research, connecting the risk factors to fishing, comes from the recreational angling literature. A summary of the available information derived from the mortality evidence catalogue for the key risk factors in presented in Table 6.

For the purpose of using the risk factors to assess mortality risk of a given fishery, we have created risk factor scoring tables for each of the five risk factors (e.g., Table 7). Each scoring table is accompanied by a separate table that summarizes the key information (i.e., sources and results) used to generate the values used in the scoring tables (e.g., Table 8). An additional accompanying table lists other considerations relevant to an understanding of the complexities of FRIM with an emphasis on factors that can either modify the scoring level or the relationship between the risk factor and mortality risk itself (e.g., Table 9). Each of the three different table types is explained in more detail below. The large amount of detail provided in each scoring table is designed to allow these tables to stand alone and be used independent of this document.

Scoring tables:

The common features of the scoring tables include:

- *Definition* – The definition of the risk factor in question as it relates to its use in evaluating mortality risk.
- *Method* – The information needed and guidance required to accurately assess each criteria and score the overall mortality risk.
- *Mortality risk range and risk score* – A major criterion for risk factor selection was the ability to scale the factor at different levels against a risk of mortality. For each factor, mortality was binned into six levels, 1 representing the best case scenario (i.e., highly unlikely that the factor will contribute to mortality: 0 to 5%), and 6 being the worst case scenario (i.e., high

probability that the factor at this level will be a major contributor to a substantial rate of mortality: 45 to 100%). Scores of 2, 3, 4, and 5 are equally distributed in 10% increments between 5% and 45%. The larger bin size range for Level 6 reflects the high uncertainty associated with the more severe impacts of these factors on mortality risk. The small bin size of 0 to 5% reflects the high confidence that the risk of mortality is minimal at Level 1.

- *Scoring criteria* – This matches a specific mortality risk range and risk score to a specific set of conditions that can be assessed in a given fishery. Each individual factor may have more than one criteria type for which to reflect the overall severity of response. For example, capture has separate criteria types depending on the generic gear type. The method section of the table provides guidance on how to select the overall score when multiple criteria types are provided. The scaling within some of the criteria types are non-linear, reflecting the non-linear responses that can occur with physiological stress responses (e.g., to air exposure).
- *Rationale and risk factors* – This describes the main rationale behind the scoring of the risk factor. The rationale section also indicates the relevant sections in the document to find the supporting information. The likelihood of some of the factors being relevant to the major fishing types are also presented, where appropriate.
- *Notes* – This provides additional information important to using the scoring table correctly. The information is required to score the mortality risk in a manner that is consistent with our current understanding of how fish respond to different stressors. Plus, it provides further clarification for the intended purpose of each table.

Information sources tables:

The information sources tables represent a quick reference to key information sources, including primary references, grey literature, and unpublished data. For each source, the key empirical or main qualitative result is presented. These sources were the primary providers of information used to generate the actual values for each scoring criteria type. However, it was not possible to provide an exact reference source for each box associated with each criteria type. Therefore, some level of interpolation was required, and this varied across risk factors, depending on the availability of evidence (e.g., see Table 6). The primary scientific support for the judgement required to interpolate values comes from the factor analysis (Chapter 2). The information source tables are designed to be readily updated as new research becomes available and gaps are filled. We recommend including studies that also challenge the current scoring systems to reduce the potential for confirmation bias.

Factor modifying tables:

The factor modifying tables present a list of factors and associated rationale that have the potential to either modify the severity of a scoring criteria level or modify the relationship between a given risk factor and the mortality risk. The information on factors that affect the severity of the response will help to both interpret the existing scores for specific fisheries, as well as aid in scoring the appropriate level for a given fishery in the absence of direct measures. For example, if you have no direct injury data for a given fishery, but you do have information on the gear and method variants, you could make inferences regarding the severity and type of injury that may occur. The list of factors that have the potential to actually modify the relationship between the risk factor and overall mortality risk represent some of the current uncertainty in the scoring tables. For example, we know that revival techniques can modify the relationship between handling time and mortality, but we do not have enough information at this point to adjust the scoring. Knowing which factors have the potential to modify the fish response to the risk factor would help direct future research. The factor analysis has more details on the connection between modifying factors, fish response, and mortality risk (Chapter 2).

Table 6. The number of studies on anadromous salmonids that include mortality estimates relevant to FRIM; the numbers are divvied up by fishery type, key risk factors and species. The information is summarized from the mortality evidence catalogue (section 3.4).

	Fishery Type	Gill net	Beach seine	Dip net	Purse seine	Angling	Troll	Trap	Total
	Total # of studies	34	18	5	11	72	16	24	162
FACTOR	Capture	13	10	3	1	21	8	2	51
	Handling	5	4	1	1	11	6	1	30
	Injury	8	7	1	3	28	11	3	50
	Water Temp	11	13	4	5	49	10	10	97
	Predators	7	2	-	2	1	2	1	11
SPECIES	Coho	12	5	2	4	12	10	4	36
	Chinook	9	4	1	2	12	7	6	35
	Sockeye	14	13	1	6	5	1	4	33
	Pink	-	-	-	-	-	-	1	2
	Chum	2	2	-	1	-	1	2	7
	Steelhead	6	3	-	1	2	-	4	11
	Rainbow	-	1	1	-	14	1	-	19
	Atlantic	6	-	-	-	21	-	4	31
	Other	6	-	-	-	14	2	-	15

4.2.1 Capture

Table 7. Mortality risk scoring table for the capture risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to capture time, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factor are provided in Table 8.

Mortality Risk Range	Risk Score	Gill Net	Hook	Seine	Trap
0 to 5%	1	0-3min	0-3min	0-10min	0-10min
5 to 15%	2	3-10min	3-10min	10-30min	10-60min
15 to 25%	3	10-20min	10-20min	30-60min	60-120min
25 to 35%	4	20-40min	20-40min	60-120min	120-720min
35 to 45%	5	40-60min	40-60min	120-720min	12-48hr
45 to 100%	6	>1hr	>1hr	>12hr	>48hr

Definition: The mortality risk of capture is reflected in capture time. Capture time extends from the potential for a fishery encounter to handling of the catch; for a gill net it is the time from initiation of net deployment to complete net retrieval; for hook fisheries, time from hooking to landing; for seine nets, time from initiation of net deployment to net bagging (commencement of crowding); for traps, time from deployment and trap check.

Method: Select the main capture type and then select median capture time that best represents the fishery in question.

Rationale: An encounter with a fishery causes physiological stress due to threat perception, confinement, and physical contact with fishing gear and catch; attempts to evade and escape capture typically use anaerobic pathways associated with exhaustive exercise (fight response; see 2.3.1); longer capture times increase the physiological stress of the encounter, the duration of contact with gear and/or catch, and the potential for more exhaustive bouts (i.e., increased number of fight or flight responses); increased physiological perturbation can result in acute mortality (e.g., acidosis) and latent mortality (e.g., due to limited swim performance during physiological recovery). The differences in the capture time scoring criteria by gear type is based on variation in the magnitude of the physiological response (see 2.4.1); for gill nets the stress of capture includes a high number of fight responses, physical contact, and potential for suffocation (operculum restricted); for hook and line capture stress includes high number fight responses and physical contact; for seines capture stress includes confinement and some physical contact and exhaustive exercise; for traps capture stress includes confinement with limited potential for exhaustive bouts.

Notes: Meant to reflect both acute and latent mortality risk; longer capture times increase the risk of injury and this risk should be reflected in higher injury scores; longer capture times may increase the risk of depredation (depending on gear type and capture environment) and predation (depending on release environment; see 2.8.6), and this risk should be reflected in higher predator scores.

Table 8. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for capture time. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data. Brackets contain the gear type that the results are most relevant to.

Information Source	Empirical Result
Amy Teffer (UBC) unpublished data, Vancouver, B.C.	difference in mortality for 20sec vs. 20min ~30% (Gill Net)
Black 1957	15min vigorous exercise ~25% mortality (Gill Net, Hook)
Buchannan et al. 2002	difference in mortality for 40min vs. 140min ~50% (Gill Net)
Candy et al. 1996	difference 15-30min vs >30min ~30% (Seine)
Cook et al. 2014	higher capture stress response lead to higher risk of mortality (Trap)
Donaldson et al. 2011	24hr captive fish 30-40% higher mortality than immediate release (Hook, Seine, Trap)
Dunn and Lincoln 1978	24hr trap fish had immediate mortality of 22% chinook to 4% coho marine; only 52% Chinook good condition (Trap)
Gale et al. 2011	>3min high stress response (Gill Net, Hook)
Hargreaves and Tovey 2001	>60min = 55% vs 25% for 10 to 20min (Gill Net)
Parker and Black 1959	max lactate response after 10 mins exercise, hook time linked to lactate, lactate linked to mortality (Hook)
Portz et al. 2006	review of short-term confinement and physiological stress response (Seine, Trap)
Raby et al. 2015c	24hr holding coho ~20% mortality after 24hr in holding study (2X rate of immediate release) (Seine, Trap)
Robinson et al. 2013	>3min high stress response (Gill Net, Hook)
Robinson et al. 2015	difference <10min seine vs 10min seine + 3min sim hook + 30min trap ~30% increase in mortality (Seine)
Thompson et al. 1971	12hr set 70% immediate mortality, plus 80% post-release within 8 days (Gill Net)
Tufts et al. 1991	complete exhaustion equilibrium loss after 10min (Gill Net, Hook)
Vincent-Lang et al. 1993	no difference mortality <1min fight time; higher mortality >1min (Hook)
Wedemeyer and Wydoski 2008	<5min osmo and metabolic responses within normal tolerance ranges (Hook)
Wood et al. 1983	physiological mechanism relating severe exercise to mortality (All)

Table 9. A list of factors, with associated rationale, that have the potential to either modify the capture duration or the capture time-mortality risk relationships. The former can assist in scoring the risk factor. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2).

Capture duration

Modifying Factor	Rationale
catch size	large catch sizes can increase hook time (commercial troll) and set time (gill net)
fish size	large fish take longer to land and increase potential for repeat exhaustive exercise (e.g., rod and reel)
hydrology	sea state can influence capture time
mesh type	longer nets, longer set times (e.g., gill net, seine net)
species	fight time can vary by species
terminal tackle	line weight influence on duration of capture (e.g., rod and reel)

Capture - mortality relationship

Modifying Factor	Rationale
hydrology	fishing or current speed could alter sustained swimming and potential for exhaustive exercise (Seine)
maturity	potential resilience to stressors with increase maturation
pre-encounter condition	disease state, recaptures, would decrease resilience to capture stress
sex	differences in physiological stress response, females more vulnerable
water temperature	exacerbate physiological perturbation, infection, and disease progression

4.2.2 Handling

Table 10. Mortality risk scoring table for the handling risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to handling time, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factors are provided in Table 11.

Mortality Risk Range	Risk Score	Total Time Handling in Air	Total Time Handling in Water
0 to 5%	1	0-10sec	0-3min
5 to 15%	2	10-60sec	3-10min
15 to 25%	3	1-2min	10-40min
25 to 35%	4	2-3min	40-60min
35 to 45%	5	3-5min	60-180min
45 to 100%	6	>5min	>180min

Definition: Handling from capture until release of all non-retained catch; this includes but separates handling time in air and handling time in water; handling incorporates all instances of crowding, sorting and revival.

Method: Select the median total handling durations in air and in water that best represent the fishery in question; then, select the highest score of the two handling types.

Rationale: Handling causes further physiological stress due to crowding, physical contact with gear and/or catch, revival confinement, and exposure to air; attempts to escape handling typically use anaerobic pathways associated with exhaustive exercise (see 2.3.1); longer handling times increase the physiological stress of the encounter (see 2.4.2), the duration of physical interaction with gear and/or catch, and the potential for more exhaustive bouts (i.e., increased number of fight or flight responses); increased physiological perturbation can result in acute mortality (e.g., acidosis) and latent mortality (e.g., due to limited swim performance during physiological recovery); air exposure impedes aerobic respiration, limiting oxygen availability for physiological recovery and thereby exacerbating the physiological imbalance and prolonging recovery; extended air exposure can also cause direct acute mortality (see 2.4.4).

Notes: Meant to reflect both acute and latent mortality risk; confinement herein refers to the enclosure of catch without forcing physical interaction with gear and/or catch, whereas crowding refers to confinement and forced physical interaction; handling time in water (i.e., crowding) typically does not apply to loose seines (e.g., experimental fishing) or traps unless overloaded; the duration of this confinement (not crowding) in these examples would be reflected in capture time; longer handling times increase the risk of injury and this risk should be reflected in higher injury scores; longer handling times may increase the risk of predation (see 2.8.6), and this risk should be reflected in higher predator scores; air exposure can occur in all types of fisheries, but total time handling in water is typically an issue for seine fisheries.

Table 11. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for handling. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data.

Handling in air

Information Source	Empirical Result
Cook et al. 2014	high stress response from 2min air exposure and 40min water handling linked to survival
Cook et al. 2015	extensive review, >1min air exposure leads to higher mortality, should avoid
Ferguson and Tufts 1992	<1min exposure high mortality (contrast with Raby et al. 2013)
Gale et al. 2011	1min air ventilation impairment; 50% lost equilibrium, lactate increased
Gale et al. 2014	1min air increased lactate, lactate increased impairment, and air exposed higher mortality ~10%
K. Cook (UBC) unpublished data, Vancouver, B.C.	>1min air reflex impairment, >4 min of air exposure, 50% loss of orientation, orientation related to mortality; marine 10C
Raby et al. 2013	>1min equilibrium loss starts, >6min air 80% fish loss equilibrium, physiological disturbance also related to length of air exposure; spawning ground 12C
Raby et al. 2015a	3min air exposure = severe impairment of reflexes, resulted in most fish becoming unresponsive; 46% exhibited complete loss of reflexes (RAMP score = 1.0) and a further 45% lost four of five reflexes (0.8).
Schreer et al. 2005	less than 60sec air is best. More than that impacts swim performance, more than 120sec= further impairment, 50% not able to swim at all

Handling in water

Information Source	Empirical Result
Donaldson et al. 2012	15min crowding in seine increased mortality 13% after 5 days
Raby et al. 2012	reflex impairment increased with handling time (>6 to 9min), higher reflex impairment related to delayed mortality
Raby et al. 2015a	2min vs 15min of crowding large effect blood stress parameters; 18% mortality difference at 15C between 2 vs 15min
Robinson et al. 2013	increased handling time via ventilation assistance higher mortality
Robinson et al. 2015	<3min vs 5 to 45min handling in water + min air ~30% increase delayed mortality
Waring et al. 1992	9min crowding (net) - increased mortality and elevation of cortisol, glucose, lactate, osmolality, monovalent ion levels in 11C seawater

Table 12. A list of factors, with associated rationale, that have the potential to either modify the handling time or the handling time-mortality risk relationships in either air or water. The former can assist in scoring the risk factor. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2).

Handling duration

Modifying Factor	Rationale
capture time	long capture times increase probability of longer handling times for revival
capture time	short capture times can increase handling time if fish not fatigued
catch composition	target to non-target ratios can influence sort times
catch size	influences total handling time - lengthy for large catches; stress of repeated physical contact with conspecifics
gear type	removal times vary by gear type, e.g., barbed hook, hang ratio
gear variation	ramping versus brailing with influence both air and water handling times
handler technique/experience	potential for more exhaustive bursts (fight response) during handling; physiological stress of fish being touched; inexperienced handlers can lead to lengthier handling times/higher stress
revival method	trade-off may only benefit poor condition fish

Handling - mortality relationship

Modifying Factor	Rationale
catch size	catch density can potentially influence the magnitude of the stress response
dissolved oxygen	overcrowding can lower dissolved oxygen availability (e.g., beach seine); on-board tanks
maturity	potential resilience to stressors
pre-encounter condition	recaptures (i.e., stressed fish) can be more sensitive handling
sex	differences in physiological stress response
suspended sediment	abrasion and injury to gills (e.g., beach seine)
water temperature	exacerbate physiological perturbation, infection and disease progression

4.2.3 Injury

Table 13. Mortality risk scoring table for the injury risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to injury, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factor are provided in Table 14.

Mortality Risk Range	Risk Score	Scale Loss	Tissue Damage	Blood Loss	Fin Damage	Puncture Wound
0 to 5%	1	<5% of body	no visible damage	none or negligible blood loss	none	surficial; non-critical location
5 to 15%	2	5-10% of body	minor/surficial abrasions	minor blood loss	minor fraying; a few fins	shallow; non-critical location
15 to 25%	3	10-25% of body	minor bruising (compression) wounds; gear markings	moderate blood loss; no gill damage	fraying; multiple fins	deep; non-critical location
25 to 35%	4	25-35% of body	small open wound (e.g., muscle); distinct gear markings	moderate blood loss; gill damage	fin split base to tip; damage at base	surficial; critical location
35 to 45%	5	35-50% of body	large open wound; severe compression or gear markings	heavy blood loss	partial fin loss	shallow (hook left in); critical location
45 to 100%	6	>50% of body	deep wound (e.g., bone); critical location; crushing injury	pulsatile blood loss (damage to artery)	loss of pectoral, pelvic, caudal fin	deep (hook removed); critical location

Definition: Visible injury likely to have occurred as a result of any aspect of a fishery encounter.

Method: Select the median injury score that best represents the fishery. Consider all five types of injury; if information is available for more than one type of injury, then select the highest score; non-critical locations include the head, body surface, fin and mouth cartilage; critical locations include the eye, roof of mouth, tongue, esophagus, gills and all major organs.

Rationale: Interaction with gear, catch, handler and/or predator during a fishery encounter can result in visible injuries that can be linked to acute mortality (e.g., severe blood loss) and latent mortality (e.g., infection). Severity ranking in the scoring criteria reflects an incremental increase in the risk of mortality (see 2.3.2 and 2.3.4). The scoring criteria links to mortality via stress response (all types), exsanguination (blood loss, scale loss, wounds), reduce mobility (tissue damage, fin damage), and increased risk of infection and disease (all types).

Notes: Meant to reflect both acute and latent mortality risk; there is variability in the level of interpretation required for each injury type due to the lack of empirical data (e.g., lots of information on puncture wounds but limited on fin damage).

Table 14. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for injury. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data.

Information Source	Empirical Result
A. Bass (UBC) unpublished data, Vancouver, B.C.	fin damage indicative of delayed post-release mortality, multiple fins, split fins
Baker & Schindler 2009	adult sockeye salmon with moderate to severe gill net injury experienced prespawn mortality; maturation and reproductive fitness were reduced in fish with minor injuries
Batholomew and Bohnsack 2005	review of 53 papers dealing with rod and reel fisheries, hook location a major determinant of mortality
Butler and Loeffel 1972	sublegal Chinook: higher immediate mortality if hooked in gills or isthmus (36.4% and 19.3% respectively) while hooked elsewhere: 2.9-7.4% immediate mortality
Cowen et al. 2007	critical hook locations and bleeding were significant predictors of immediate mortality; list of critical hook locations
Diewert et al. 2002	scale loss of Chinook significant impact on immediate mortality; Chinook and coho immediate mortality with blood loss: no bleeding (3.3%), light (6.6%), moderate (37.9%), heavy (87%)
DuBois & Dubielzig 2004	38% mean 48hr mortality for gill hook, vs less than 5% for jaw, mouth or external snag
Lindsay et al 2004	hooking mortality rates (delayed) for each of five anatomical locations (jaw, 2.3%; tongue, 17.8%; eye, 0.0%; gills, 81.6%; and esophagus-stomach, 67.3%); Chinook fresh water
Mongillo 1984	major review: deep hooks removed = up to 93% mortality vs deep hooks left in =33% mort; greater than 45-95% mort of those hooked in critical locations (eye, esophagus, gills, tongue); mortality less than 20% for jaw, mouth
Muoneke and Childress 1994	review of hooking locations in association with mortality, supporting critical locations
Rosseland et al. 1982	25% descaled Atlantic salmon mortality 20% (fresh water) to 60% (salt water) after 9 days
Schill 1996	rainbows delayed mortality (weeks), deep hook cut-line 40-55% mortality; deep hook removed 66-83% mortality, light hook 0-5%, high mortality >50% for major organ hook locations
Thompson et al. 1971	40% descaled sockeye marine ~50% mortality vs. ~15% controls 6 days
Vincent-Lang et al. 1993	~5 day coho; mortality gills or esophagus hook location 5X higher than other head locations, higher scale loss and bleeding higher mortality
Wertheimer 1988	Chinook marine troll 5 day mortality: hook in gills had highest mortality (50-90.8%), followed by eyes (16-26%), lowest (0-6%) maxillary; more severe wounding and shorter Chinook had higher mortality

Table 15. A list of factors, with associated rationale, that have the potential to either modify the injury response or the injury-mortality risk relationships. The former can assist in scoring the risk factor. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2).

Injury response

Modifying Factor	Rationale
bait or lure	influences hook depth or ingestion of hook
catch composition	mixed catches of size or coarse fish can influence injury
catch size	increase capture and handling time, increasing probability of injury
catch size	large catches can increase bag or trap densities - lead to crushing injuries
gear variation	brailing versus ramping can influence crushing injuries, scale loss
hook location	anatomical location that hook enters body
hook size	ratio of fish size to hook size
hydrology	sea state can influence decision to ramp or brail
hydrology	flow conditions for safety can influence bag density
landing net	scale loss for marine especially, connected to size
mesh size	ratio of fish size to mesh size, can either increase or decrease injury
predators	longer capture times increase risk of wounding from predators

Injury - mortality relationship

Modifying Factor	Rationale
predators	attractant
pre-encounter condition	pre-existing condition altering experience and response
salinity	scale loss impact reduced in isotonic water (10-12ppt)

4.2.4 Water Temperature

Table 16. Mortality risk scoring table for the water temperature risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to water temperature, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factor are provided in Table 17.

Mortality Risk Range	Risk Score	Water Temperature	Detailed Rationale for Level
0 to 5%	1	<14°C	warm water diseases suppressed; high oxygen content of water during capture and post-release recovery; lower oxygen debt resulting from exhaustive exercise
5 to 15%	2	14-16°C	optimum aerobic scope for most salmon; low virulence strains of pathogens can start to proliferate
15 to 25%	3	16-18°C	reduced capacity to recover from exercise; infection rates increase, elevated risk of disease
25 to 35%	4	18-20°C	reduced aerobic scope, limits recovery exhaustive exercise, increase vulnerability; proliferation of warm water pathogens and higher disease risk
35 to 45%	5	20-22°C	collapse of aerobic scope, reduce mobility, increased predation risk; inability to deal with stress, increase risk of infection
45 to 100%	6	>22°C	cessation of migration, vulnerable to predation/recapture; suppressed stress response, increase infections and very high disease risk

Definition: Temperature experienced during and after a fishery encounter.

Methods: Calculate the expected average water temperature a fish would experience for 72 hours after the initiation of fishing encounter and match the value to a risk score.

Rationale: Water temperature plays a pivotal role in modulating fish survival independent of FRIM (see 2.3.4 and 2.8.1). The mortality risk reflected in this table represents the incremental change in mortality risk associated with fishing at different water temperatures, above the natural effect that water temperature would have on survival. The scoring reflects the incremental cost of recovery from exhaustive exercise, change in in physiological stress response, and the increased risk of infection and disease associated with warmer water temperatures.

Notes: Meant to reflect both acute and latent mortality risk.

Table 17. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for water temperature. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data.

Information Source	Empirical Result
Eliason et al. 2011	optimum aerobic scope curves for Fraser sockeye populations ~16C; >19-21C scope reduced; >21C 50% collapse
Eliason et al. 2013	detailed examination of cardio-respiratory performance with increasing temperatures highlighting decrease performance from thermal optimums of 16 to 17C.
Gale et al. 2011	no equilibrium loss at 13C or 19C for reference fish, but simulated capture >50% loss at 19C and 21C; ~50% mortality within 72hr at 21C for all treatment fish, zero mortality for 13C and 19C for 72hr
Gale et al. 2013	major review paper on consistent increase in temperature dependent mortality for release mortality
Gale et al. 2014	19C 30% higher than 13C, 16C 10% higher than 13C
Jain and Farrell 2003	repeat critical swim speed performance lower at 15C than 9C
Jeffries et al. 2012b	transcriptome response to high temperatures 14C vs.19C indicating overlap of immune response and water temperature
Martins et al. 2011	13C to 20C tag data, modelled differences between marine and river tag fish represent the incremental cost of water temperature, main basis for above relationship
McCullough et al. 2001	literature review of thermal impacts on salmon indicating problems above 18C for adult migration
Miller et al. 2014	review of pathogens associated with temperature increase and immunosuppression and high temperatures
Raby et al. 2015a	~10% mortality of fish at 15C vs 10C for 2 and 15min crowding
Robinson et al. 2013	16C - control fish ~10- 40% higher survival than simulated captured fish

Table 18. A list of factors, with associated rationale, that have the potential to either modify the temperature experience or modify the temperature-mortality risk relationship. The former will assist in measuring the temperature experience. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2).

Temperature experience

Modifying Factor	Rationale
species	behaviour differences in fish response to capture, fall-back, thermal refuge

Temperature - mortality relationship

Modifying Factor	Rationale
injury	opportunistic infections
physiological condition	severity of physiological perturbation
salinity	lower D.O. in marine versus fresh water for same temperature, higher basal MO2 in salt water
size/age	possible to have size-dependent temperature effects
species	species-specific thermal optima; population specific potential

4.2.5 Predators

Table 19. Mortality risk scoring table for the predator risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to predators, provides the definition of this context-specific risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factors are provided in Table 20.

Mortality Risk Range	Risk Score	Evidence of Predation	Evidence of Predator Abundance
0 to 5%	1	<5% loss rate; or very few visual signs	none or very few observed and a non-marine mammal area
5 to 15%	2	>5% loss rate; consistent observations but dispersed	few observed and marine mammal area
15 to 25%	3	>15% loss rates; low landing rate, some net damage	daily observations of a few predators
25 to 35%	4	>25% loss rates; with consistent evidence of predation	daily observations of a few habituated predators
35 to 45%	5	>35% loss rate; extensive net damage and terminal gear loss	daily observation of a lots of predators
45 to 100%	6	>45% loss rate; high persistent evidence of predation	daily observation of a lots of habituated predators

Definition: Change in the likelihood of predator encounters as a result of a fishery.

Method: Select the scores that best represent both the direct evidence of predation and the direct evidence of predator abundance and use the higher of the two scores. Loss rate refers to depredation estimates only, not landing rates although they are likely related.

Rationale: Unambiguous relationship between the interaction with predators and the mechanism and likelihood of mortality (see 2.8.6); the observable impact and/or abundance of predators in the environment reflects the potential risk of an encounter and ultimately mortality. High depredation loss rate would also imply a higher escapee or release mortality risk, which is why it could be relevant to both drop-off and release mortality risk. Key sources of information to score the table are based on Raby et al. 2014 and judgment.

Notes: Meant to be used for all forms of predator-related mortality (e.g., depredation and post-release predation); assessed risk can be different for depredation (i.e., drop-off mortality) and predation (i.e., release mortality).

Table 20. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for predators. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data.

Information Source	Empirical Result
Diewert et al. 2002	summary of information to estimate encounter rate of predators for recreational troll fishing
French and Dunn 1973	estimates of depredation rates for gill nets marine linked to predator observation and loss evidence
Gilhousen 1989	estimates a 25% escapee wounding rate for troll fisheries using
Nagasawa 1998	impact of salmon sharks on ocean mortality of Pacific Salmon, fisheries catch of salmon sharks synchronized with those of salmonids
Raby et al. 2014b	review of the importance of predation in assessing the mortality of fish released from fishing gear
Thompson et al. 1971	evidence of depredation rates from sockeye caught in gill nets

Table 21. A list of factors, with associated rationale, that have the potential to modify the likelihood of predation. This will assist in estimating the predator score. See the factor analysis for more details (Chapter 2).

Predator experience

Modifying Factor	Rationale
bait	act as an attractant
capture time	increased exposure for gill net and hook; increased duration will increase severity of fish response
catch size	predator saturation with larger catch size; evidence of impact in proportion to catch size
gear type	fish in gill nets or on hooks more vulnerable
handling	type and increased duration will increase severity of fish response
injury	predator attractant
species	predator choice and preference, e.g., large Chinook
water temperature	can change predator species composition

4.3 CONCLUSIONS AND APPLICATIONS

A key feature of all the tables associated with scoring mortality risk is the maintenance of a strong connection between the fishing-related factors, the risk factors, the fish-centric response and the mortality risk (see Figure 4). The capture risk scoring tables (Tables 7-9) are designed to assess the risk of mortality as it relates to the physiological stress experienced during the entire capture event of a fishery encounter. The handling risk scoring tables (Tables 10-12) are designed to assess the risk of mortality as it relates to the stress that occurs during handling. The risk of injury associated with capture and handling is accounted for in the injury risk scoring table (Tables 13-15). The injury is separated from capture and handling for the scoring system to reflect the large variability in injury that exists across fisheries. There is continuity in the assessment of risk as it progresses from an assessment of the inherent physiological stress associated with capture and handling to the potential for injury by a variety of means during the capture, handling, and release processes. The water temperature risk scoring tables (Tables 16-18) reflect the incremental cost associated with the magnified stress response that occurs during capture and handling, as well as the potential for more injury related infections associated with fishery encounters in warm water. The predator risk scoring tables (Tables 19-21) represent a separate but key environmental risk that can, under certain situations, be very relevant to both drop-off and release mortality.

An important consideration during the development of these risk scoring tables was the ability to provide a means of assessing fisheries that was fair and transparent when applied across all types of fishing. This allows for direct comparisons of risk for individual factors across a variety of fisheries. Focusing on generic risk factors that have a clear directional response between different fishing activities and mortality risk, provides insight into areas of potential mitigation. For example, any mitigation efforts that are known to reduce the score for a given factor will translate into a lower mortality risk. Moreover, using estimates of percent mortality risk provides a clear indication of the approximate benefit or harm to changing fishing practices. This attempt at providing a magnitude of effect gives more guidance than simply stating that there is a change in risk level without attempting to provide some quantitative estimate of what the actual change in risk level means in terms of mortality risk. Although we have captured a sizable portion of the variability in FRIM, we do acknowledge there is a large amount of uncertainty in the results, and gaps in our understanding. We encourage the development and modification of these risk scoring tables in the future; as new evidence becomes available these tables can be updated to reflect the ever-growing knowledge base (see section 4.4 for further recommendations). In the accompanying research document we have taken the next step of developing an overall risk assessment that can estimate the cumulative impact of the five risk factors (see Patterson et al. 2017).

4.4 UNCERTAINTIES AND KNOWLEDGE GAPS

The final objective of this paper is to identify uncertainties and knowledge gaps in the information that is currently available to inform estimates of FRIM for Pacific salmon. Although the literature on incidental mortality is vast (literally hundreds of studies), when one considers the factors that can influence the outcome (e.g., species, gear type, handling technique, water temperature, and predator abundance), it quickly becomes apparent that there are many gaps in our knowledge. In fact, much of our understanding of FRIM comes from borrowing insight from other species, fisheries or systems. However, with such extrapolation comes uncertainty. The identification of these knowledge gaps provides information for both describing the limitations of the existing evidence base and directing the efforts of future research. Here, we provide a list of key knowledge gaps related to both understanding FRIM and applying estimates related to Pacific salmon.

- There are multiple uses of FRIM in fisheries management and stock assessment that vary in application across different fisheries. This variability results in a multitude of additional information requirements that can include estimates of stock-age composition, encounter rates, fleet profiles, and compliance rates that need to be considered before mortality rates are actually generated.
- Very little is known about the extent to which fish encounter a fishery and avoid or escape the gear, or die and drop-out. There is a need to quantify such encounters and, for those fish that avoid or escape the fishery, to examine the effect of the interaction on fish condition and ultimately survival.
- Virtually nothing is known about the frequency and consequence of multiple fishery interactions for an individual fish.
- Robust FRIM estimates are just one component of an informed stock assessment and management program. Knowledge of Pacific salmon life history and population size and dynamics are also important considerations.
- Pacific salmon are diverse and vary in their physiology, behaviour, and morphology among species, populations, sexes, and individuals. Comparative species- and population-specific studies will provide information on the inherent variability of FRIM. Notably, there is a lack of information in the primary literature on pink and chum salmon, in general, and North Coast populations of any Pacific salmon species. Determining the extent to which inherent diversity influences mortality outcomes as well as the extent to which generalizations can be made (rather than needing empirical studies on all possible fishery interaction combinations) should be a priority.
- Water temperature is a major modifier of mortality through a variety of physiological and disease-related mechanisms, yet much remains unknown about its ability to mediate the fish response to fishery encounters. Given that water temperatures are expected to continue to rise, research related to water temperature and incidental mortality (and the underlying mechanisms) should be a priority.
- There is a need to identify the temporal trajectories of disease development as it relates to FRIM. Future work should look to better understand disease dynamics and pathogenicity as it relates to the magnitude of stress and injury, population variability, location (e.g., fresh water or marine), and water temperature.
- Information on the connection between water temperature and the ability to recover from repeated bouts of exhaustive exercise is lacking. Predicting the ability of fish to recover at different water temperatures is valuable to the interpretation of post-release predation risk (including species and size effects).
- Very little evidence currently exists in the primary literature to fully quantify the impact of predation across different fisheries and species, even though the biological mechanism of depredation and post-release predation on Pacific salmon is clearly understood. Research is needed in both fresh water and marine realms.
- The focus of this document is to identify factors that influence FRIM to better understand the extent to which fishery interactions are negative (i.e., particularly problematic), this type of mechanistic assessment provides additional opportunity. Fisheries that are assessed to be particularly problematic, could be modified to reduce the risk of FRIM. For example, if it becomes clear that air exposure beyond a given threshold will lead to high mortality, then changes can be made to relevant fisheries to reduce air exposure, however this requires

identifying air exposure thresholds for mortality of different Pacific salmon species, particularly as they relate to water temperature, maturity and exhaustion level, are needed.

- Although there have been a reasonable number of studies in fresh water, much less is known about FRIM (and associated drivers and modifiers) in estuarine and marine waters. Also, many of the studies conducted in fresh water need to be replicated to address the potential for location-specific variation in FRIM given differences in environmental conditions, organismal physiology, and predator abundance.
- Much effort has been devoted to the development and validation of various vitality indices. However, there is need for additional validation across a broader suite of species/populations and contexts to determine if it can be used to predict FRIM in the field. In addition, there is need to explore whether some form of rapid injury assessment could be combined with a vitality indices (usually based on reflexes) to better predict mortality.
- Further work is required to match fish revival approaches to higher mortality risk or lower vitality scores. This would connect the research on mortality mechanisms with the potential for mitigation. The need for estimates of delayed mortality for marine revival studies fits in this future work recommendation.
- Accurate, objective estimates of FRIM rates are inherently difficult to obtain. Even when such estimates are available from individual studies, the limitations of study design make it necessary to interpret the studies that generate them with caution and require informed consideration of the context-specificity and possible biases associated with them.
- A major knowledge gap associated with all FRIM studies is the extent to which FRIM represents an incremental level of mortality/risk over background natural mortality. As such, there is a need for additional research efforts that refine methods for quantifying natural mortality and FRIM.
- There are practical and scientific limitations to the methods currently available for estimating all components of drop-off and release mortality, including biases introduced through captive observation studies and tagging/biotelemetry studies. Currently, researchers are forced to use these approaches that introduce uncertainty and bias.
- A key difficulty in synthesizing the body of literature related to FRIM is the inconsistent use of terminology to describe different types of mortality. This project provides a basis for standardization of the terminology which will aid future research and mitigation efforts, but does not help interpret or elucidate differences amongst existing studies in the literature.

4.5 RECOMMENDATIONS

The aforementioned challenges with studying incidental mortality are not limited to Pacific salmon. In 2014, ICES initiated a working group on “Methods for Estimating Discard Survival”. The group was established in response to a request from the European Commission to address the urgent need for guidance on methods for estimating discard survival. There were practical and scientific limitations to the methods available for estimating discard survival, which included tagging and biotelemetry, captive observation, and vitality assessments. The working group has convened on several occasions, and commissioned white papers (involving some of the co-authors on this CSAS report) which will underpin fisheries management decisions. Those products are relevant to the Pacific salmon arena and will hopefully provide more certainty and best practices for conducting or interpreting incidental mortality studies in the future.

There is need to prioritize risk for different fisheries to help direct effort towards those stocks/species/fisheries that may be particularly problematic. However, FRIM estimates represent only part of the puzzle given that it must be integrated with knowledge of fishing effort and stock/population size. Thinking about FRIM from the perspective of the fisher may be useful for ensuring the relevancy of study methods and interpreting the basis for a given value (e.g., why is it low or high). Although the purpose of this research document is about simply documenting FRIM and its modifiers, resource managers are also interested in modifying human behaviour such that regulated or unregulated actions and outreach effort are dynamic and provide opportunity for solving problems. FRIM is inherently about a problem and documenting it rather than on trying to solve it. FRIM estimates represent the first step, especially when combined with knowledge of stock size, species, and open ocean focus, towards evidence-based fisheries management. However, FRIM is really about mortality while sub-lethal effects may also be relevant and equally cryptic (Cooke et al. 2013). Any efforts to study FRIM should extend beyond the given site/species/fishery mortality values and include sub-lethal endpoints.

The approach we adopted to assess FRIM was fish-centric, focussed on understanding how a fish responds, with an emphasis on examining factors relevant to understanding FRIM, in contrast to simply focusing on mortality estimate literature. This enabled us to broaden our evidence base by amalgamating and distilling decades of FRIM-relevant research. It also allows for flexibility to alter estimates in response to changes in how a fishery is executed and/or defined. The incorporation of intrinsic and/or extrinsic factors in our approach provides the potential to make new FRIM predictions following changes in the environment and/or condition of fish. The efforts expended here to amass and extract data on FRIM were extensive, but still identified major knowledge gaps. This document, and any risk assessments based on it, should be revisited as more information becomes available. Indeed, this report and the accompanying databases should be considered living documents and updated regularly.

To date, there have been few attempts to integrate information on FRIM into an ecological risk assessment. Risk assessment is a decision-support tool that evaluates the impacts of various anthropogenic or environmental stressors (in this case, those relevant to FRIM) on ecological components (e.g., species or populations), and recognizes that not all components are affected in the same way when exposed. Examples of such a tool being applied to other species experiencing FRIM-related issues include southern bluefin tuna (*Thunnus maccoyyi*; Matsuda et al. 1998) and some shark species (e.g., Chin et al. 2010; Cortes et al. 2010; Gallagher et al. 2012).The generation of mortality risk values for individual risk factors used here is the most comprehensive and detailed approach for FRIM that we are aware of. This represents a significant advance in both understanding FRIM and in predicting FRIM across different fisheries. As such, this paper is not meant as the definitive guide on FRIM but a transparent, defensible, and rigorous evaluation of the primary evidence base for making future decisions about FRIM. The next step is presented in an accompanying document (Patterson et al. 2017) and it is to estimate the cumulative effect from the individual risk factors as part of an overall risk assessment that can be used in both fisheries management and stock assessment.

5 GLOSSARY

Acute mortality: Mortality of fish in direct and immediate response to a capture or handling stressor. Most likely associated with severe injuries, such as exsanguination, or mortality from severe exercise or extreme hyperactivity.

Avoidance mortality: Mortality of fish that encounter fishing gear but actively avoid the gear without direct physical contact, resulting in fatigue and stress (e.g., gear avoidance through difficult passage areas) and eventual death.

Barbless hook: A hook from which all barbs have been removed—either filed off or pinched flat against the shaft. The shaft of a hook is the straight part between the eye and the bend.

Bycatch (or by-catch): Various definitions from unintended catch (fish not sold or kept for personal use) to discarded catch plus the incidental catch. Does not refer to fish released alive in catch and release fishing.

Captured: A fish is considered captured when it is under the complete control of the fisher; when the fish brought alongside the boat or shore (related to landed). Not to be confused with hooked or tangled where the fish may escape or drop-out.

Capture time: Time from potential gear encounter to capture: e.g., deployment to bag net, gill net deployment to drum, hook time to boat/shore, periods between trap check.

CM – Catch mortality, or 'CM': Is captured (target or non-target) fish that died during capture or during handling and that would otherwise have been intended for live release. CM is akin to on-board mortality in our list of the seven components of FRIM.

Catch-and-release: Usually in reference to recreational angling, the act of catching a fish with the intention to release it alive.

Commercial fishing: The act of fishing with the intent to make a profit from selling the harvested fish to consumers.

Confinement stress: The stress associated with limiting the movement of fish via entrapment, but without persistent physical contact with the gear or other fish. All trap and seine net fisheries as well as holding studies elicit some level of confinement stress.

Context-specific risk factor: A risk factor that is not applicable or relevant to all fisheries, but whose impact can both dominate (e.g., predator) or mitigate (revival methods) the overall mortality response. (See Risk Factor).

Crowding stress: The stress associated with confining fish into even tighter spaces such that the fish are in repeated and direct contact with fishing gear or other fish. Corralling fish to the point of physical interaction results in increased number of fight responses and higher probability of injury associated with physical contact (e.g., scale loss).

Cryptic mortality: A mortality event that is not observed.

Delayed post-release mortality (> 24 hr): Mortality of fish that occurs more than 24 hours after released alive that can be attributed to back to the fishing event.

Depredation: Fish that die as a result of predators directly removing fish from fishing gear during the capture process; this does not include the predation of released fish.

Discard mortality: The mortality of catch that is returned to the water (non-retained), includes fish that are released alive or dead.

Discarded catch: The proportion of the total catch that is returned to the water – may be either target species or non-target species.

Drop-off mortality: Combined mortality of avoidance, escape, depredation, and drop-out mortalities (i.e., mortality of all fish that encounter gear but do not make it on-board). Also referred to as non-catch mortality (NCM).

Drop-out: Fish that die and drop out of the fishing gear prior to landing (e.g., drop-out of gill nets). Fish that fall off alive would be escapees.

Escape mortality: Mortality of fish that actively escape after contact with fishing gear prior to landing (e.g., escape from a hook or gill net).

Fishery: The activities leading to and resulting in the capturing of fish. A fishery is typically characterized by the species caught, the fishing gear used, and the area of operation.

Fishery encounter: The time and events associated with a fish perceiving and responding to the different events associated with a fishery (e.g., gear deployment, capture, handling, and release).

Fishing mortality: Death of fishes that can be directly or indirectly attributed to fishing activities, includes drop-off, retained catch, and release mortality.

Fishing-related incidental mortality (FRIM): Refers to any mortality that occurs as a result of an encounter with fishing gear that is not included in the retained catch estimates.

Generic risk factor: A mortality risk factor that is relevant to all fisheries. (See Risk Factor)

Handling time: Total time spent being handled from the point of capture to release; includes bag time for seines, removal times from gear, hand netting, and time sorting.

Hooking mortality: Death of fishes attributable to capture with standard hook and line fishing gears (baited hooks, artificial baits with various hook types, and arrays).

Immediate mortality: Immediate (or initial) mortality is defined as capture-related death that is observable immediately up capture and during the handling process. We have used this term as being synonymous with on-board mortality.

Incidental catch: Catch of non-target species. Also often called bycatch.

Landing: When a fish is brought aboard the boat or streamside, under complete control of the fisher, similar to capture for most fisheries except for seine fisheries (i.e., capture ends at crowding in water, but landing involves being on board).

Latent mortality: Latent effects of capture or handling that eventually lead to mortality (e.g., related to chronic stress).

Natural bait: Foodstuff or other natural substance (other than wood, cotton, wool, hair, fur or feathers) that is used as bait.

NCM – Non-catch mortality, or 'NCM': Refers to fish that die prior to being landed, this includes the mortality components of avoidance, escape, depredation, and drop-outs.

Non-target catch: Species that are captured but are not the intended or target catch.

On-board mortality: Mortality of captured fish; this observable mortality includes fish that are dead on landing or die on board prior to release (e.g., during sorting or in holding tanks) and is synonymous with immediate mortality.

Play time: total time spent on hook and line. (See capture time)

PRM – Post-release mortality or 'PRM': Represents death from a fishing event at some point after release by a fisher. PRM is akin to short-term and delayed post-release mortality components. It also includes mortality associated with shakers, fall-outs, or slippage.

Release mortality: Mortality of fish captured but not retained, includes immediate (i.e., on-board) mortality of fish that are not retained, along with short-term post-release mortality and delayed post-release mortality.

Risk assessment: An analytical approach for estimating risk.

Risk: In the context of FRIM, it is defined as the probability that a Pacific salmon not targeted for retention will die due to exposure to one or more identified factors related to fishing.

Risk factor: In the context of FRIM, a factor whose effect on the probability of a fish surviving a fishery encounter can be quantified across a severity of impact scale.

Set time: time from net deployed to net bagged (i.e., capture). (See capture time)

Shaker/shake-off: Fish that are captured but shaken off of the gear before being brought on board (non-target catch). These fish can be observed and associated mortalities would part of PRM.

Short-term post-release mortality (≤ 24 h): Mortality of fish that occurs up to 24 hours after released alive, that is associated with the fishery encounter.

Single barbless hook: A barbless hook with only one point. A treble hook (with three points) is not considered to be a single hook.

Slippage: Release of captured fish at water-line for seine fishing (i.e., no on-board sorting). They would be treated as a post-release but likely have lower post-release mortality rates. Also related to the spilling of fish that are captured but not landed.

Soak time: See capture time; time from first cork in to last cork out for gill nets. Represents the maximum time a fish could encounter a gill net.

Sub-lethal effects: Non-lethal injurious, physiological, behavioural, and fitness-related impacts as a result of fishing interaction that lead to reductions in future fitness via impairment to growth or reproduction. Not considered in the review.

Target catch: The species that are the primary target in a given fishery. The target catch can either be retained or released.

Terminal fishery: Fishery in a river or near the mouth of a river where returning salmon pass through or congregate near to and prior to spawning, and where stocks are relatively unmixed.

Vitality: A term to reflect the overall condition of a fish. It is meant as an integrative measure of the physiological state of a fish through the use of visual assessments of injury and reflex impairments.

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APPENDIX A: FACTOR ANALYSIS

A.1 SEARCH DETAILS

Table A.1. Search string used to search the Web of Science online database for factors related to FRIM. General search terms were used for the basic search and more specific terms were used to the advanced searches.

Search string	Web of Science parameters
release mortality AND fishing	basic search
release mortality AND temperature	basic search
release mortality AND fish* AND temperature effects	basic search
factors that influence release mortality AND fish*	basic search
TS= (("fishing mortality" OR "release mortality" OR "post-release mortality" OR "post release mortality") AND ("salmon" OR salmon*))	advanced search; all databases
TS= (("fishing mortality" OR "release mortality" OR "post-release mortality" OR "post release mortality") AND (fisher* OR "troll" OR "trawl" OR "catch-and-release" OR "catch and release" OR "gill-net" OR "angling" OR "seine" OR "seine-net" OR "beach seine"))	advanced search; all databases
TS=((salmon* OR "chinook" OR "pink salmon" OR "sockeye" OR "coho" OR "chum" or "trout" OR "Atlantic salmon" or "oncorhynchus") AND ("fishery" OR "angling" OR "angling event" "angled" OR "catch and release" OR "catch-and-release" OR "capture and release" OR "capture-and-release" OR "trawl" OR "seine" OR "purse seine" OR "beach seine" OR "gill-net" OR "gill net" OR "troll" OR "hook" OR "netted") AND ("mortality" OR "fate" OR "discard" OR "discard mortality" OR "post-release survival" OR "release mortality" OR "post release mortality" OR "post-release mortality" OR "mortality rate" OR "survival rate"))	advanced search; all databases

A.2 CODING SCHEME

Table A.2. Coding scheme used to systematically extract metadata information from the included articles to better understanding factors related FRIM. Information contained in the factor analysis repository tool.

Category	Column Name	Definition	Action
Reference Information	Search term key	Numbered search	1-14
	Reference no	Unique reference ID	20xxxx
	pdf	Was the pdf filed?	"pdf"
	Extracted (y/n)	Was the paper extracted in the extraction table?	y
	Citation	Full reference for bibliography	authors, year, title, source, volume, page numbers
	Publication type	Publication type	pick from drop-down list
	Pub year	Publication year	date (xxxx)
	Journal/Source	Journal, report, book source name	name of source
	Volume, issue	Volume and issue number of publication	xx(x)
	pgs	Page numbers of publication	xxx-xxx
	Authors	Authors	last names, first initials
	Title	Title	Full title
	Abstract	Full abstract if available	Full abstract
Core Topic	Salmonid related? (y=1)	Is the paper salmonid-related?	1 = yes
	Species	What species does the paper focus on?	name species
	Mort est/for RL?	Does the paper provide a mortality estimate?	1 = yes
	Key points	What are the key points?	free input
	NOTES	Noteworthy features	free input
	Relevance	How relevant is this paper?	low, med, high
Core Results	Primary factor	What is/are the primary factor(s) discussed?	list factor(s)
	Results relevant to mortality	What results are relevant to mortality estimates/predictions?	free input
	Sublethal effects/population effects	Sublethal or population effects discussed or addressed?	1 = yes or free input comments
Study	Review/ Summary	Is the paper a review or summary?	1 = yes
	Fishing-related mort estimates	Is the paper fishing-related?	1 = yes
	Non-fishery related	Is the paper not related to a fishery?	1 = yes
	Field	Was the experiment conducted in the field?	1 = yes
	Lab	Was the experiment conducted in a lab?	1 = yes
	Model/ simulation	Did the paper use a model or simulation?	1 = yes

Category	Column Name	Definition	Action
	Holding/ monitoring/ tagging	Was this a holding study? Tagging/Monitoring study?	1 (some supply monitoring period)
	Other	Other study design?	1 (list type)
Extrinsic	Temperature	Level of information on temperature as it pertains to fish health/mortality present?	1 = yes
	Depth	Level of information on depth as it pertains to fish health/mortality present?	1 = yes
	Salinity	Level of information on salinity as it pertains to fish health/mortality present?	1 = yes
	Discharge/ flow/sea state	Level of information on discharge/flow/sea state as it pertains to fish health/mortality present?	1 = yes
	Dissolved O2	Level of information on dissolved oxygen as it pertains to fish health/mortality present?	1 = yes
	Suspended Sediment	Level of information on suspended sediment as it pertains to fish health/mortality present?	1 = yes
	Other	Level of information on other locational/extrinsic factors that may pertain to fish health/mortality present?	1 = yes (list factor as inserted comment)
Intrinsic	Size	Level of information on fish size pertaining to mortality present?	1 = yes
	Age	Level of information on age pertaining to mortality present?	1 = yes
	Injury	Level of information on injury pertaining to mortality present?	1 = yes
	Sex	Level of information on sex/gender pertaining to mortality present?	1 = yes
	Species or Population	Level of information on species or population differences and mortality present?	1 = yes
	Reproductive Status	Level of information on fish reproductive status pertaining to mortality present?	1 = yes
	Metabolic Status	Level of information on metabolic status and mortality present?	1 = yes
	Stress physiology	Level of information on physiological state and mortality present?	1 = yes
	Osmoregulatory Status	Level of information on osmoregulatory status and mortality present?	1 = yes
	Predation	Level of information on predation or depredation present?	1 = yes
	Behaviour	Level of information on behaviour of fish present?	1 = yes
	Disease or Pathogens	Level of information on disease/pathogens/infection present?	1 = yes
General Fishing	Air Exposure	Level of information on air exposure present?	1 = yes

Category	Column Name	Definition	Action
Factors	Capture Time/Soak time	Level of information on capture time, soak time, play time etc. Present?	1 = yes
	Handling time	Level of information on handling time present?	1 = yes
	Handling technique/ experience	Level of information on level of experience or technique of fisher/fish handler present?	1 = yes
Gear Interaction	General interaction	Level of information on the general interaction of fish with fishing gear present?	1 = yes
	Hook type	Level of information on hook type used present?	1 = yes
	Hook location	Level of information on anatomical hooking location present?	1 = yes
	Hook effects - general	Level of information on the effects of hooking, in general, present?	1 = yes
	Bait vs lure	Level of information on the effect of using bait/lure present?	1 = yes
	Other	Other gear interaction presented? Net effects?	1 = yes
Gear Type	Net/Trap	Net or trap fishery-related?	1 = yes
	Type of gear	What type of fishing gear was used?	text
	Hook and Line	Hook and line fishery-related?	1 = yes
Recovery Method	Boxes/ bags/ tanks	Recovery method employed, such as bags, boxes or tanks?	1 = yes
	Temp-control	Was the recovery environment temperature-controlled?	1 = yes
	Ventilation assistance	Was venting or ventilation assistance provided?	1 = yes
Catch Details	Density of fish/catch	Level of information on catch density?	1 = yes
	Catch composition	Level of information on species composition of catch?	1 = yes
	Crowding	Level of information on crowding?	1 = yes
	Confinement	Level of information on confinement?	1 = yes

APPENDIX B: MORTALITY EVIDENCE CATALOGUE

B.1 SEARCH DETAILS

B.1.1 Web of Science

The following search string comprised of English search terms was used to query the Thomson Reuters Web of Science online database:

Table B.1. Search string used to search the Web of Science online database. The search was split into two periods to accommodate the large return size.

Search string	Time restriction	Returns [date]
TS = ((“salvelinus” OR “oncorhynchus” OR “salmo*” OR “pink salmon” OR “pinks” OR “coho” OR “chinook” OR “chum” OR “sockeye” OR “steelhead” OR “trout” OR “masu” OR “atlantic salmon”) AND (“fishery” OR “fishing” OR “fisheries” OR “netted” OR “capture*” OR “catch-and-release” OR “capture-and-release” OR “angling” OR “angled” OR “gillnet*” OR “gill net*” OR “dipnet*” OR “dip net*” OR “seine*” OR “beachseine*” OR “beach seine*” OR “purseseine*” OR “purse seine*” OR “troll*” OR “trawl*” OR “hook*” OR "tagged" OR "tag" OR "holding”) AND (“mortality” OR “mortality rate” OR “release mortality” OR “post-release mortality” OR “postrelease mortality” OR “post-release survival” OR “postrelease survival” OR “survival rate” OR “discard*” OR “discard mortality” OR “fate” OR “migration success” OR “died” OR “death” OR “depredat*” OR “drop-out*” OR “dropout*” OR “by-catch*” OR “bycatch*” OR “drop-off*” OR “dropoff*”))	1864–1999	1,929 [30/10/2015]
	2000–Present	2,181 [30/10/2015]

The *Advanced Search* function was used to search *All Databases* in Web of Science; the databases that were available at the time using the Simon Fraser University publication subscription included the following:

- Web of Science ™ Core Collection
- BIOSIS Citation Index ℠
- BIOSIS Previews ®
- KCI-Korean Journal Database
- MEDLINE ®
- SciELO Citation Index
- Zoological Records ®

All Web of Science databases were searched in response to the following observations:

- The timespan of article availability in the Web of Science ™ Core Collection is limited relative to the other databases; for example, returns from the North American Journal of

Fisheries Management was available from 2001 onward in the Core Collection compared to 1981 onward when All Databases were searched.

- There appeared to be a broader assortment of grey literature and report returns available within the All Database search.

Web of Science was unable to handle the large number of returns (i.e., greater than 5,000 returns) and therefore, provided an approximate return list that contained replicates. To circumvent this issue, we segmented our *Timespan* search into two periods:

- 1864-1999
- 2000-Present

Additional Web of Science search nuances:

- Can't use two wildcards in a single search term
- Hyphens are interpreted as spaces

B.1.2 Fisheries and Oceans Canada Waves

The following search string comprised of English search terms was used to query the DFO WAVES online database:

Table B.2. Search string used to search the DFO WAVES online database.

Search string	**Returns [date]**
((subjects:salvelinus OR subjects:oncorhynchus OR subjects:salmo* OR subjects:pink salmon OR subjects:coho OR subjects:chinook OR subjects:chum OR subjects:sockeye OR subjects:steelhead OR subjects:trout OR subjects:masu) AND (subjects:gill net* OR subjects:dip net* OR subjects:troll* OR subjects:trawl* OR subjects:hook* OR subjects:*seine* OR subjects:*seining) OR (subjects:longlin* OR subjects:angling OR subjects:angled OR subjects:capture* OR subjects:catch OR subjects:tag* OR subjects:rod OR subjects:reviv* OR subjects:caught OR subjects:handl*)) la:ENG	4,835 [18/01/2016]

The search was conducted under the following database conditions:

- DFO Libraries: All Libraries
- Publication Type: All
- Format: All
- Year: All
- Language: English

As identified in the search string, the subject field – defined by WAVES as a search of the title, subject, series and abstract – was searched for each search term. Exploration of the search parameters for this database indicated that all available bibliographic information for a given holding was evaluated in a subject field search.

Unlike the Web of Science search string, the 'outcome' search terms were not included in the string. Following exploration of the database, there was concern that narrowing the search further (i.e., including 'outcome' search terms) would compromise the retrieval of relevant documents, specifically due to the variability among holdings in the amount of bibliographic information available.

Additional WAVES search nuances:

- Most of the search flexibility came from adjusting the search string in the *Simple Search*, not the drop-down menus and field options in the *Advanced Search*
- Quotations do not search for an exact term (e.g., "gill net") amidst a list of terms connected by 'OR'; however, the search string can be modified to search for both words (i.e., as if connected by 'and'; e.g., subjects: gill net*), but the search will not be limited to the exact phrase (i.e., the words may be in different sentences)
- E.g., trap – found words with trap as a hyphenated addition (e.g., fish-trap), but not as part of a word (e.g., bootstrap)
- E.g., gill*net* – found all variants (e.g., gill-net(s), gillnet(s)), except when the asterisks would have represented a space (e.g., gill net(s))

Article pre-screening protocols:

We used MS-Excel formulas to broadly filter the article returns at the title and abstract level prior to employing the screening protocols documented in section 4.1.1.

B.1.3 Specialist Websites

The following specialist organization websites were searched for relevant primary or grey literature:

- Alaska Department of Fish and Wildlife
    - Chinook Salmon Research Initiative
    - Alaska Board of Fisheries
    - Fishing and Subsistence Database
- National Oceanic and Atmospheric Administration
- Oregon Department of Fish and Wildlife
- Pacific Salmon Commission
- Pacific States Marine Fisheries Commission
- United States Fish and Wildlife Service
- Washington Department of Fish and Wildlife

B.1.4 Information Request

The following call-for-information request was distributed via email by Fisheries and Oceans Canada (DFO) Fisheries Management on December 10, 2015. Fisheries Management distributed a reminder email on January 26, 2016. This information is available upon request to David Patterson, DFO.

Subject: Call for documented evidence related to fishing-related incidental mortality for Pacific salmon

We are requesting your help in accessing documented evidence on fishing-related incidental mortality of Pacific salmon. This includes reports on drop-outs, depredation, immediate mortality, and post-release mortality from all salmon directed fisheries.

This is a Canadian Science Advisory Secretariat (CSAS) project on fishing-related incidental mortality for Pacific salmon designed to evaluate the documented evidence available to inform estimates of mortality that are not related to catch retention. The intent is to provide information to support the estimation of fisheries-induced mortality rates which are used in pre-season planning, in-season management, and post-season assessment of salmon fisheries. This review and any advice arising from it will be provided to management for their consideration.

We are currently reviewing key factors that can influence the mortality of fish that encounter fishing gear. Plus, we are conducting a systematic review of mortality rates present in the existing literature, both primary and grey (e.g. consultant reports, unpublished studies, technical reports & manuscript reports). We are requesting your help in accessing the grey literature (i.e. pdf or hard copies of old reports related to incidental mortality) in particular.

Please contact me if you have any questions or would like to discuss this request further. Also, please consider forwarding this request to others who may have access to relevant materials.

We request that all reports are received by January 31st, 2016 to allow time for proper review and inclusion in the CSAS research document.

If you have any questions about the review process, or are interested in receiving published results of the outcome, please do not hesitate to contact me.

Thank you for your cooperation,
David Patterson
Research Biologist
Head, Environmental Watch Program
Science Branch
Fisheries and Oceans Canada
David.Patterson@dfo-mpo.gc.ca
(604) 666-5671

The members of the following groups received the call-for-information request from DFO Fisheries Management. The group descriptions reported herein were provided by Fisheries Management (Kelly Binning, DFO Fisheries Management, 401 Burrard Street, Vancouver, BC, personal communication, 2016).

Salmon Working Group members

The Salmon Working group is an internal DFO working group to develop salmon fishing plans for the Pacific Region. It is comprised of essential representatives from resource management, science, and enforcement throughout the Pacific Region and representatives from relevant branches in regional headquarters (Treaty and Aboriginal Policy Directorate, Salmon Enhancement Program) to coordinate enforcement and fishery management. This working group develops draft plans for providing fishing opportunities, incorporating feedback received from stakeholders and First Nations. Area representatives discuss issues common to all areas to develop a coordinated approach to resolving them.

Salmon Integrated Harvest Planning Committee (IHPC) members

In Pacific Region, DFO consults with and engages First Nations and other interests through a wide range of processes. For salmon, the focal point for DFO's engagement with First Nations, the harvest sectors and environmental interests is around the development and implementation of the annual IFMP. At a broad, Province-wide level, the Integrated Harvest Planning Committee (IHPC) brings together several First Nations, commercial and recreational harvesters, and environmental interests to review and provide input on the draft IFMP, as well as co-ordinate fishing plans and (where possible) resolve potential issues between the sectors. The IHPC also meets post-season to review information regarding stocks and fisheries and implementation of the IFMP" (DFO 2015, p.137).

Salmon Coordinating Committee (SCC) members

Other processes, such as the First Nations Salmon Coordinating Committee (SCC) and the Forum on Conservation and Harvest Planning, are being developed in order to facilitate dialogue between First Nations and DFO. In the case of the First Nations SCC, First Nations representatives from 13 geographical areas within BC meet with DFO resource management to discuss priority issues among BC First Nations as they relate to salmon. SCC priorities include advancing First Nations concerns related to salmon, access to salmon for FSC needs across the province and working to improve First Nations economic opportunities in salmon fisheries" (DFO 2015, pp.137-138).

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Richard, A., Bernatchez, L., Valiguette, E., and Dionne, M. 2014. Telemetry reveals how catch and release affects prespawning migration in Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 71: 1730-1739.

Rivinoja, P., Leonardsson, K., and Lundqist, H. 2006. Migration success and migration time of gastrically radio-tagged *v.* PIT-tagged adult Atlantic salmon. J. Fish Biol. 69: 304-311.

Robichaud, D. and English, K.K. 2006. Assessing in-river migration behaviour and survival of summer-run sockeye salmon caught and released in the Lower Fraser River in 2005. LGL Limited Environmental Research Associates, Pacific Salmon Foundation. (Accessed January 13, 2017)

Robinson, K.R., Hinch, S.G., Raby, G.D., Donaldson, M.R., Robichaud, D., Patterson, D.A., and Cooke, S.J. 2015. Influence of post-capture ventilation assistance on migration success of adult sockeye salmon following capture and release. Trans. Am. Fish. Soc. 144: 693-704.

Savitz, J., Bardygula-Nonn, L.G. Simpson, A., and Funk, G. 1995. Survival of smaller sport caught chinook, *Oncorhynchus tshawytscha* (Walbaum), and coho, *Oncorhynchus kisutch* (Walbaum), salmon from Lake Michigan and its management implications. Fish. Manage. Ecol. 2: 11-16.

Schill, D.J. 1996. Hooking mortality of bait-caught rainbow trout in an Idaho trout stream and a Schill hatchery: implications for special-regulation management. N. Am. J. Fish. Manage. 16: 348-356.

Schill, D.J., Griffith, J.S., and Gresswell, R.E. 1986. Hooking mortality of cutthroat trout in a catch-and-release segment of the Yellowstone River, Yellowstone National Park. N. Am. J. Fish. Manage. 6: 226-232.

Schisler, G.J. and Bergersen, E.P. 1996. Post release hooking mortality of rainbow trout caught on scented artificial baits. N. Am. J. Fish. Manage. 16: 570-578.

Schreer, J.F., Resch, D.M., Gately, M.L., and Cooke, S.J. 2005. Swimming performance of brook trout after simulated catch-and-release angling: Looking for air exposure thresholds. N. Am. J. Fish. Manage. 25: 1513-1517.

Siira, A., Suuronen, P., Ikonen, E., and Erkinaro. J. 2006. Survival of Atlantic salmon captured in and released from a commercial trap-net: Potential for selective harvesting of stocked salmon. Fish. Res. 80: 280-294.

Slater, C.H., Schreck, C.B., and Amend, D.F. 1995. GnRHa injection accelerates final maturation and ovulation/spermiation of sockeye salmon (*Oncorhynchus nerka*) in both fresh and salt water. Aquaculture. 130: 279-285.

Strange. J.S. 2012. Migration strategies of adult Chinook salmon runs in response to diverse environmental conditions in the Klamath River basin. Trans. Am. Fish. Soc. 141: 1622-1636.

Thomas, J.O., and Cahusac, B. 2012. Final Investigations into Short-term (0 to 24 h) Hooking Mortality of Sockeye (*Oncorhynchus nerka*) Caught and Released at Grassy Bar, Fraser River, British Columbia, 2011. Report prepared for the Fraser Salmon and Watersheds Program (jointly managed by the Pacific Salmon Foundation and the Fraser Basin Council) and Fisheries and Oceans Canada, Lower Fraser Area. viii + 59 p.

Thompson R.B., and Hunter, C.J. 1971. Viability of adult sockeye salmon that disentangle from gillnets. Int. N. Pac. Fish. Comm. Ann. Rep. 1971: 107-109. (Accessed January 13, 2017)

Thompson, R.B., Hunter, C.J., and Patten, B.G. 1971. Studies of live and dead salmon that unmesh from gillnets. Rep. Int. N. Pac. Fish. Comm. 1969: 109-118.

Thorstad, E.B., Næsje, T.F., Fiske, P., and Finstad, B. 2003. Effects of hook and release on Atlantic salmon in the River Alta, northern Norway. Fish. Res. 60: 293-307.

Thorstad, E.B., Naesje, T.F., and Leinan, I. 2007. Long-term effects of catch-and-release angling on ascending Atlantic salmon during different stages of spawning migration. Fish. Res. 85: 316-320.

Titus, R.G., and Vanicek, C.D. 1988. Comparative hooking mortality of lure-caught Kahontan cutthroat trout at Heenan Lake, California. Calif. Fish Game. 74: 218-225.

Tsuboi, J., and Morita, K. 2004. Selectivity effects on wild white-spotted char (*Salvelinus leucomaenis*) during a catch and release fishery. Fish. Res. 69: 229-238.

Tufts, B.L., Tang, Y., Tufts, K., and Boutilier, R.G. 1991. Exhaustive Exercise in" Wild" Atlantic salmon (*Salmo salar*): Acid-Base Regulation and Blood Gas Transport. Can. J. Fish. Aq. Sci. 48: 868-874.

Tufts, B.L., Davidson, K., and Bielak, A.T. 2000. Biological implications of “catch and release” angling of Atlantic salmon. In: Whoriskey FG, Whelan KE (eds) Managing wild Atlantic salmon. Atlantic Salmon Federation, St. Andrews, New Brunswick, pp 195–225.

Vander Haegen, G.E., Ashbrook, C.E., Yi, K.W., and Dixon, J.F. 2004. Survival of spring Chinook salmon captured and released in a selective commercial fishery using gill nets and tangle nets. Fish. Res. 68: 123-133.

Vincent-Lang, D., Alexandersdottir, M., and Mcbride, D. 1993. Mortality of Coho salmon caught and released using sport tackle in the Little-Susitna River, Alaska. Fish. Res.15: 339-356.

Warner, K. 1976. Hooking mortality of landlocked Atlantic salmon, *Salmo salar*. Trans. Am. Fish. Soc. 105: 365-369.

Warner, K. 1978. Hooking mortality of lake-dwelling landlocked Atlantic salmon, *Salmo salar*. Trans. Am. Fish. Soc. 107: 518-522.

Warner, K. 1979. Mortality of landlocked Atlantic salmon hooked on four types of fishing gear at the hatchery. Progress. Fish-Culturist. 41: 99-102.

Warner, K., and Johnson, P.R. 1978. Mortality of landlocked Atlantic salmon (*Salmo salar*) hooked on flies and worms in a river nursery area. Trans. Am. Fish. Soc. 107: 772-775.

Webb, J.H. 1998. Catch and release: the survival and behaviour of Atlantic salmon angled and returned to the Aberdeenshire Dee, in spring and early summer. Scottish Fish. Rep. 69/1998: 16 p.

Weise, M.J., and Harvey, J.T. 2005. Impact of the California sea lion (*Zalophus californianus*) on salmon fisheries in Monterey Bay, California. Fish. Bull. 103: 685-696.

Wertheimer, A. 1988. Hooking mortality of Chinook salmon released by commercial trollers. N. Am. J. Fish. Manage. 8: 346-355.

Wertheimer, A. Celewycz, A., Jaenicke, H., Mortensen, D., and Orsi, J. 1989. Size-related hooking mortality of incidentally caught Chinook salmon, *Oncorhynchus tshawytscha*. Mar. Fish. Rev. 51: 28-35.

Whoriskey, F.G., Prusov, S., and Crabbe, S. 2000. Evaluation of the effects of catch-and-release angling on the Atlantic salmon (*Salmo salar*) of the Ponoi River, Kola Peninsula, Russian Federation. Ecol. Fresh. Fish. 9: 118-125

Wilkie, M.P., Davidson, D., Brobbel, M.A., Kieffer, J.D., Booth, R.K., Bielak, A.T., and Tufts, B.L. 1996. Physiology and survival of wild Atlantic salmon following angling in warm summer waters. Trans. Am. Fish. Soc. 125: 572-280.

Wright, S. 1971. Coho shaker problem and incidental catch concept in troll fishery. Comm. Fish. Rev. 1971: 48-50.

B.3 UNOBTAINABLE ARTICLES

Total number of unobtainable articles = 18

No institutional subscription/Not able to find online = 14

Not in English = 4

Table B.3. List of unobtainable articles identified in the comprehensive search of online databases.

Full Reference	Reason
Ashbrook, C.E., Vander Haegen, G.E., Yi, K.W., and Dixon, J.D. 2003. Evaluating selective fishing: survival of spring chinook salmon captured and released from commercial nets on the Columbia River. Am. Fish. Soc. Annu. Meet. 133: 146.	No institutional subscription/Not able to find online
Bevan, D.E. 1962. Estimation by tagging of the size of migrating salmon populations in coastal waters. *In* Studies of Alaska red salmon. University of Washington Press.	No institutional subscription/Not able to find online
DeCicco, A.L. 1999. Mortality of anadromous dolly varden captured and released on sport fishing gear in Alaska. ISACF Info. Ser. 7: 107-116.	No institutional subscription/Not able to find online
Doi, Takahide, et al. 2004. Hooking mortality and growth of caught and released Japanese charr *Salvelinus leucomaenis* and masu salmon *Oncorhynchus masou masou* in experiment ponds. Nippon Suisan Gakkaishi 70.5: 706-713.	Not in English
Doi, Takahide, et al. 2005. Destiny of hooks remaining in the body of Japanese charr *Salvelinus leucomaenis* and masu salmon *Oncorhynchus masou masou*. Nippon Suisan Gakkaishi 71.3: 348-353.	Not in English
Fraser, J. 2003. Reducing gill-net mortalities of incidentally caught species: an industry perspective. Am. Fish. Soc. Annu. Meet. 133: 146.	No institutional subscription/Not able to find online
Grover, A.M., Mohr, M.S., and Palmer-Zwahlen, M.L. 2002. Hook-and-release mortality of Chinook salmon from drift mooching with circle hooks: management implications for California's ocean sport fishery. American Fisheries Society Symposium. Eds. J. A. Lucy and A. L. Studholme. American Fisheries Society. Am. Fish. Soc. Symp. 30: 39-56.	No institutional subscription/Not able to find online
Jensen, K.W. 1977. On the dynamics and exploitation of the population of brown trout, *Salmo trutta* L., in Lake Oevre Heimdalsvatn, southern Norway. Inst. Freshw. Res. Drottningholm Rep. 56: 18-69.	No institutional subscription/Not able to find online

Full Reference	Reason
Kojima, T., Iwashita, A., Mizuno, K., and Soeda, H. 1998. Estimation of physical load of fish tightened by a nylon line using autoregressive analysis of heart rate variability. Nippon Suisan Gakkaishi. 64: 999-1005.	Not in English
Loeffel, R.E. 1962. A mortality study on pre-season troll-caught silver salmon. Pac. Mar. Fish. Comm. Annu. Rep. 1961. 14: 51-52.	No institutional subscription/Not able to find online
Milne, D.J., and Ball, E.A.R. 1956. The mortality of small salmon when caught by trolling and tagged or released untagged. Fish. Res. Board Can. Pac. Prog. Rep. 106: 10-13.	No institutional subscription/Not able to find online
Smith, G.W. 1992 Salmon movements in relation to river flow: Estuarine net catches of adult Atlantic salmon (*Salmo salar* L.) and tracking observations. Inst. Fish. Manage. Annu. Study Course. Proc. 22: 37-46.	No institutional subscription/Not able to find online
Stringer, G. E. 1967. Comparative hooking mortality using three types of terminal gear on rainbow trout from Pennask Lake, British Columbia (*Salmo gairdneri*). Can. Fish Cult. 39: 17-21.	No institutional subscription/Not able to find online
Taguchi, K. 1961. A trial to estimate the instantaneous rate of natural mortality of adult salmon (*Oncorhynchus* spp.) and the consideration of rationality of offshore fishing. I. Chum Salmon (*Oncorhynchus keta*). Bull. Jpn. Soc. Sci. Fish. 27: 963-971.	No institutional subscription/Not able to find online
Taguchi, K. 1961. A trial to estimate the instantaneous rate of natural mortality of adult salmon (*Oncorhynchus* sp.) and the consideration of rationality of offshore fishing II. For red salmon (*O. nerka*). Bull. Jpn. Soc. Sci. Fish. 27: 972-978.	Not in English
Thompson, D. 1985. Interactions between grey seals and salmon fisheries. Inst. Fish. Manage. Annu. Study Course Proc. 16: 142-151.	No institutional subscription/Not able to find online
Turunen, T., and Suuronen, P. 1996 Hooking mortality of small brown trout and grayling in Finnish rivers catch-and-release fisheries. Boreal Environ. Res. 1: 59-64.	No institutional subscription/Not able to find online
Wendler, H.O. 1959 Migration and fishing mortality rates of Columbia River spring chinook salmon in 1955. Wash. Dept. Fish. Fish. Res. Pap. 2: 71-81.	No institutional subscription/Not able to find online

B.4 RELEVANT REVIEWS

Bartholomew, A., and Bohnsack, J.A. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Rev. Fish Biol. Fish. 15: 129-154.

Cook, K.V., Lennox, R.J., Hinch, S.G., and Cooke, S.J. 2015. Fish out of water: how much air is too much? Fisheries. 40: 452-461.

Cooke, S.J., and Sneddon, L.U. 2007. Animal welfare perspectives on recreational angling. Appl. Anim. Behav. Sci. 104: 176-198.

Cooke, S.J., and Suski, C.D. 2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Aquat. Conserv.: Mar. Freshwater Ecosyst. 14(3): 299-326.

Cooke, S.J., Danylchuk, A.J., Danylchuk, S.E., Suski, C.D., and Goldberg, T.L. 2006. Is catch-and-release recreational angling compatible with no-take marine protected areas? Ocean Coastal Manage. 49: 342-354.

Cooke, S.J., Hinch, S.G., Donaldson, M.R., Clark, T.D., Eliason, E.J., Crossin, G.T., Raby, G.D., Jeffries, K.M., Lapointe, M., Miller, K., Patterson, D.A., and Farrell, A.P. 2012. Conservation physiology in practice: how physiological knowledge has improved our ability to sustainably manage Pacific salmon during up-river migration. Philos. Trans. R. Soc. B. 367: 1757-1769.

Cooke, S.J., Raby, G.D., Donaldson, M.R., Hinch, S.G., O'Connor, C.M., Arlinghaus, R., Danylchuk, A.J., Hanson, K.C., Clark, T.D., and Patterson, D.A. 2013. The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation and relevance to stake holders. Fish. Manage. Ecol. 20: 268-287.

Cox-Rogers, S., Gjernes, T., and E. Fast. 1999. A review of hooking mortality rates for marine recreational coho and Chinook salmon fisheries in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 99/127. 16 p. (Accessed January 13, 2017)

Davis, M.W. 2010. Fish stress and mortality can be predicted using reflex impairment. Fish and Fish. 11: 1-11.

Gale, M.K., Hinch, S.G., and Donaldson, M.R. 2013. The role of temperature in the capture and release of fish. Fish Fish. 14: 1-33.

Hinch, S.G., Cooke, S.J., Farrell, A.P., Miller, K.M., Lapointe, M., and Patterson, D.A. 2012. Dead fish swimming: a review of research on the early migration and high premature mortality in adult Fraser River sockeye salmon *Oncorhynchus nerka*. J. Fish Biol. 81: 576-599.

Johnson, J.E., Patterson, D.A., Martins, E.G., Cooke, S.J., and Hinch, S.G. 2012. Quantitative methods for analyzing cumulative effects on fish migration success: a review. J. Fish Biol. 81: 600-631.

Lewin, W.C., Arlinghaus, R., and Mehner, T. 2006. Documented and potential biological impacts of recreational fishing: insights for management and conservation. Rev. Fish. Sci. 14: 305-367.

Martins, E.G., Hinch, S.G., Patterson, D.A., Hague, M.J., Cooke, S.J., Miller, K.M., Lapointe, M.F., English, K.K., and Farrell, A.P. 2011. Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River sockeye salmon (*Oncorhynchus nerka*). Global Change Biol. 17: 99-114.

Portz, D.E., Woodley, C.M., and Cech Jr., J.J. 2006. Stress-associated impacts of short-term holding on fishes. Rev. Fish Biol. Fish. 16: 125-170.

Raby, G.D., Donaldson, M.R., Hinch, S.G., Clark, T.D., Eliason, E.J., Jeffries, K.M., Cook, K.V., Teffer, A., Bass, A.L., Miller, K.M., Patterson, D.A., Farrell, A.P., and Cooke, S.J. 2015. Fishing for effective conservation: context and biotic variation are keys to understanding the survival of Pacific salmon after catch-and-release. Integr. Comp. Biol. 55: 554-576.

Raby, G.D., Packer, J.R., Danylchuk, A.J., and Cooke, S.J. 2014. The understudied and underappreciated role of predation in the mortality of fish released from fishing gears. Fish Fish. 15: 489-505.

Ricker, W.E. 1976. Review of the rate of growth and mortality if Pacific salmon in salt water, and noncatch mortality caused by fishing. J. Fish. Res. Board Can. 33: 1483-1524.

Schill, D.J., and Scarpella, R.L. 1997. Barbed hook restrictions in catch-and-release trout fisheries: a social issue. North Am. J. Fish. Manage. 17: 873-881.

Taylor, M.J., and White, K.R. 1992. A meta-analysis of hooking mortality of nonanadromous trout. North Am. J. Fish. Manage. 12: 760-767.

B.5 EXCLUDED ARTICLES

Table B.4. Explanation of the rejection codes used to present the reason for article exclusion.

No. Rejected	Code	Explanation
5	No relevant population	E.g., juveniles
12	No relevant intervention	No fishery encounter
89	No relevant outcome	No original or empirical mortality rates provided

Table B.5. List of articles screened and excluded at the full-text level. The rejection codes used to explain the reason for article exclusion are decoded in Table B.4.

Full Reference	Reason
Aarestrup, K., Jepsen, N., Rasmussen, G., Økland, F., Thorstad, B., and Holdensgaard, G. 2000. Prespawning migratory behaviour and spawning success of sea-ranched Atlantic salmon, *Salmo salar* L., in the River Gudenaa, Denmark. Fish. Manage. Ecol. 7: 387-400.	No relevant outcome
Aarestrup, K., Jepsen, N., Koed, A., and Pedersen, S. 2005. Movement and mortality of stocked brown trout in a stream. J. Fish Biol. 66: 721-728.	No relevant intervention
Baillie, S.J., Taylor, J.A., and Watson, N.M. 2015. 1999 telemetric studies of coho salmon at Black Creek, Vancouver Island. Can. Manuscr. Rep. Fish Aquat. Sci. 3055: viii + 38p.	No relevant outcome
Baker, M.R., Kendall, N.W., Branch, T.A., Schindler, D.E., and Quinn, T.P. 2011. Selection due to nonretention mortality in gillnet fisheries for salmon. Evol. Appl. 4: 429-443.	No relevant outcome
Baker, M.R., Swanson, P., and Young, G. 2013. Injuries from non-retention in gillnet fisheries suppress reproductive maturation in escaped fish. PLoS ONE. 8: e69615.	No relevant outcome
Baker, M.R., Schindler, D.E., Essington, T.E., and Hilborn, R. 2014. Accounting for escape mortality in fisheries: implications for stock productivity and optimal management. Ecol. Appl. 24: 55-70.	No relevant outcome
Barton, L.H. 1992. Tanana River, Alaska fall chum salmon radio telemetry study. Fish. Res. Bull. 92-01: vii + 22 p.	No relevant outcome
Bielak, A.T. 1996. A discussion document on the implications of catch-and-release angling for Atlantic salmon, with particular reference to water temperature-related river closures. DFO Can. Sci. Advis. Sec. Res. Doc. 96/117. i + 17.	No relevant outcome

Full Reference	Reason
Boyce, I. 1999. Upper Yukon radio-telemetry tracking station installation and spawning ground sampling/tag recovery. DFO final report. Project RE-09-98-01: 17 p.	No relevant outcome
Brenden, T.O., Jones, M.L., and Ebener, M.P. 2010. Sensitivity of tag-recovery mortality estimates to inaccuracies in tag shedding, handling mortality, and tag reporting. J. Great Lakes Res. 36: 100-109.	No relevant population
Bromaghin, J.F., Underwood, T.J., and Hander, R.F. 2007. Residual effects from fish wheel capture and handling of Yukon River fall chum salmon. N. Am. J. Fish. Manage. 27: 860-872.	No relevant outcome
Burnley, T., Stryhn, H., and Hammell, K.L. 2012. Post-handling mortality during controlled field trials with marine grow-out Atlantic salmon, *Salmon salar* L. Aquaculture. 368-369: 55-60.	No relevant intervention
Carline, R.F., Beard Jr., T., and Hollender, B.A. 1991. Response of wild brown trout to elimination of stocking and to no-harvest regulations. N. Am. J. Fish. Manage. 11: 253-266.	No relevant outcome
Caudill, C.C., Daigle, W.R., Keefer, M.L., Boggs, C.T., Jepson, M.A., Burke, B.J., Zabel, R.W., Bjornn, T.C., and Peery, C.A. 2007. Slow dam passage in adult Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality? Can. J. Fish. Aquat. Sci. 64: 979-995.	No relevant outcome
Cooke, S.J., Schreer, J.F., Dunmall, K.M., and Philipp, D.P. 2002. Strategies for quantifying sublethal effects of marine catch-and-release angling: insights from novel freshwater applications. Am. Fish. Soc. Symp. 30: 121-134.	No relevant outcome
Cooperman, M.S., Hinch, S.G., Crossin, G.T., Cooke, S.J., Patterson, D.A., Olsson, I., Lotto, A.G., Welch D.W., Shrimpton, J.M., Van Der Kraak, G., and Farrell, A.P. 2010. Effects of experimental manipulations of salinity and maturation status on the physiological condition and mortality of homing adult sockeye salmon held in a laboratory. Physiol. Biochem. Zool. 83: 459-472.	No relevant outcome
Cox-Rogers, S., Gjernes, T., and E. Fast. 1999. A review of hooking mortality rates for marine recreational coho and Chinook salmon fisheries in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 99/127. 16 p.	No relevant outcome
Davis, M.W. 2007. Simulated fishing experiments for predicting delayed mortality rates using reflex impairment in restrained fish. ICES J. Mar. Sci. 64: 1535-1542.	No relevant population
Dempson, J.B., Furey, G., and Bloom, M. 2001. Effects of catch-and-release angling on Atlantic salmon on the Conne River. Fish. Manage. Ecol. 9: 139-147.	No relevant outcome

Full Reference	Reason
DFO. 1957. The spawning of pink salmon in the Fraser River system above Hope -1955. DFO. 20 p	No relevant outcome
DFO. 2012. Temperature threshold to define management strategies for Atlantic salmon (*Salmo salar*) fisheries under environmentally friendly conditions. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/019. (Accessed January 13, 2017)	No relevant outcome
Di Novo, S.C., Nagtegaal, D.A., and Ryall, P.J. 1997. Estimation of total incidental mortality (chinook, coho and steelhead) associated with seine fishing in Johnstone Strait, Sabine Channel and Juan de Fuca Strait from 1987 to 1990. Can. Data Rep. Fish. Aquat. Sci. No. 1014: 61 p.	No relevant outcome
Dieperink, C. 1995. Depredation of commercial and recreational fisheries in a Danish fjord by cormorants, *Phalacrocorax carbo sinensis*, Shaw. Fish. Manage. Ecol. 2: 197-207.	No relevant outcome
Diewert, R.E., Nagtegaal, D.A., and Hein, K. 2005. A comparison of the results of the 1998 Georgia Strait creel survey with an independent observer program. Can. Manuscr. Rep. Fish. Aquat. Sci. 2716. vii + 39 p.	No relevant intervention
Dunfield, R. 1962. Salmon tagging in the Saint John area drift net fishery. DFO report. 21 p.	No relevant outcome
Fenichel, E.P., Tsao, J.I., and Jones, M.L. 2009. Modeling fish health to inform research and management: *Renibacterium salmoniarum* dynamics in Lake Michigan. Ecol. Appl. 19: 747-760.	No relevant outcome
Ferter, K., Borch, T., Kolding, J., and Vølstad, J.H. 2013. Angler behaviour and implications for management – catch-and-release among marine angling tourists in Norway. Fish. Manage. Ecol. 20: 137-147.	No relevant population
Foerster, R.E. 1954. Sex rations in sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 11: 988-997.	No relevant outcome
Fretwell, M.R. 1989. Homing behavior of adult sockeye salmon in response to a hydroelectric diversion of homestream waters at Seton Creek. Int. Pac. Salmon Fish. Comm. Bull. XXV: 38 p.	No relevant outcome
Fulmer, B.A., and Ridenhour, R.L. 1967. Jaw injury and condition of king salmon. Calif. Fish Game. 53: 282-285.	No relevant outcome
Gallagher, C.P., and Dick, T.A. 2010. Historical and current population characteristics and subsistence harvest of Arctic char from the Sylvia Grinnell River, Nunavut, Canada. N. Am. J. Fish. Manage. 30: 126-141.	No relevant outcome

Full Reference	Reason
Gallagher, A.J., Serafy, J.E., Cooke, S.J., and Hammerschlag, N. 2014. Physiological stress response, reflex impairment, and survival of five sympatric shark species following experimental capture and release. Mar. Ecol. Prog. Ser. 496: 207-218.	No relevant outcome
Gearin, P.J., Melin, S.R., DeLong, R.L., Kajimura, H., and Johnson, M.A. 1994. Harbor porpoise interactions with a chinook salmon set-net fishery in Washington State. Rep Int. Whaling Comm. Special Issue 15: 427-438.	No relevant population
Hansen, L.P. 1980. Tagging and recaptures of net marked and undamaged Atlantic salmon in two sea localities and two rivers in Norway. ICES C.M. 1980/M:33. 8 p.	No relevant intervention
Hansen, M.J., Ebener, M.P., Schorfhaar, R.G., Schram, S.T., Schreiner, D.R., Selgeby, J.H., and Taylor, W.W. 1996. Causes of declining survival of late trout stocked in U.S. waters of Lake Superior in 1963-1986. Trans. Am. Fish. Soc. 125: 831-843.	No relevant outcome
Henry, K.A. 1977. Estimating natural and fishing mortalities of chinook salmon, *Oncorhynchus tshawytscha*, in the ocean, based on recoveries of marked fish. NOAA Fish Bull. 76: 45-57.	No relevant outcome
Hildén, M. 1997. Boundary conditions for the sustainable use of major fish stocks in the Baltic Sea. Ecol. Econ. 20: 209-220.	No relevant outcome
Holbrook, C.M., Perry, R.W., Brandes, P.L., and Adams, N.S. 2013. Adjusting survival estimates for premature transmitter failure: a case study from the Sacramento-San Joaquin Delta. Environ. Biol. Fish. 96: 165-173.	No relevant outcome
Hunter, C.J., Patten, B.G., and Thompson, R.B. 1972. Viability of mature sockeye salmon that disentangle from gillnets. Int. N. Pac. Fish. Comm. Annu. Rep. 1972: 79-80.	No relevant outcome
Hyvärinen, P., Heinimaa, S., and Rita, H. 2004. Effects of abrupt cold shock on stress responses and recovery in brown trout exhausted by swimming. J. Fish Bio. 64: 1015-1026.	No relevant intervention
Jonsson, T., Setzer, M., Pope, J.G., and Sandström, A. 2013. Addressing catch mechanisms in gillnets improves modeling of selectivity and estimates of mortality rates: a case study using survey data on an endangered stock of Arctic charr. Can. J. Fish. Aquat. Sci. 70: 1477-1487.	No relevant outcome
Keefer, M.L., Bjornn, T.C., Peery, C.A., Tolotti, K.R., Ringe, R.R., Keniry, P.J., and Stuehrenberg, L.C. 2002. Migration of adult steelhead past Columbia and Snake River dams, through reservoirs and distribution into tributaries, 1996. Idaho Coop. Fish Wildl. Res. Unit Tech. Rep. 2002-2: vii + 176 p.	No relevant intervention

Full Reference	Reason
Keefer, M.L., Clabough, T.S., Jepson, M.A., Naughton, G.P., Blubaugh, T.J., Joosten, D.C., and Caudill, C.C. 2015. Thermal exposure of adult chinook salmon in the Willamette River basin. J. Therm. Biol. 48: 11-20.	No relevant outcome
Königson, S., Fjälling, A., Berglind, M., and Lunneryd, S.G. 2013. Male grey seals specialize in raiding salmon traps. Fish. Res. 148: 117-123.	No relevant outcome
Koski, W.R., Alexander, R.F., and English, K.K. 1996. Distribution, timing, fate and numbers of chinook salmon returning to the Nass River watershed in 1993. Can. Manuscr. Rep. Fish. Aquat. Sci. 2371: xi + 143 p.	No relevant outcome
Lasater, J.E., and Haw, F. 1961. Comparative hooking mortality between treble and single hooks on silver salmon. Pac. Mar. Fish. Comm. Bull. 5. 73-76.	No relevant outcome
Latta, W.C. 1963. Semiannual estimates of natural mortality of hatchery brook trout in lakes. Trans. Am. Fish. Soc. 92: 53-59.	No relevant outcome
Laughton, R. 1991. The movements of adult Atlantic salmon (*Salmo salar* L.) in the River Spey as determined by radio telemetry during 1988 and 1989. Scottish Fish. Res. Rep 50: 1-14.	No relevant outcome
Lawson, P.W., and Sampson, D.B. 1996. Gear-related mortality in selective fisheries for ocean salmon. N. Am. J. Fish. Manage. 16: 512-520.	No relevant outcome
Lynch, B., and Edgington, J. 1986. Stikine River studies: Adult salmon tagging, population investigations, and side scan sonar operations, 1983. Alaska Dep. Fish Game Data Rep. 171: v + 73p.	No relevant outcome
Macdonald, J.S., Foreman, M.G.G., Farrell, T., Williams, I.V., Grout, J., Cass, A., Woodey, J.C., Enzenhofer, H., Clarke, W.C., Houtman, R., Donaldson, E.M., and Barnes, D. 2000. The influence of extreme water temperatures on migration Fraser River sockeye salmon (*Oncorhynchus nerka*) during the 1998 spawning season. Can. Tech. Rep. Fish. Aquat. Sci. 2326: 117 p.	No relevant intervention
MacKay, D.C.G., Howard, G.V., and Killick, S.R. 1943. Sockeye salmon tagging at Sooke and Johnstone Strait. International Pacific Salmon Fisheries Commission Annual Rep. 43-1: 21-35.	No relevant outcome
MacKay, D.C.G., Howard, G.V., and Killick, S.R. 1944. Sockeye salmon tagging at the salmon banks, Iceberg Point, Lummi Island, and the Sand Heads. International Pacific Salmon Fisheries Commission Annual Rep. 44-1: 29-49.	No relevant outcome
Major, R.L. 1984. Yield loss of western Alaska chinook salmon resulting from the large catch by the Japanese salmon mothership fleet in the North Pacific Ocean and Bering Sea in 1980. N. Am. J. Fish. Manage. 4: 414-430.	No relevant outcome

Full Reference	Reason
Manzer, J.I., Morley, R.B, and Girodat, D.J. 1985. Terminal travel rates for Alberni Inlet sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 1367: 19p.	No relevant outcome
Martins, E.G., Hinch, S.G., Patterson, D.A., Hague, M.J., Cooke, S.J., Miller, K.M., Robichaud, D., English, K.K., and Farrell, A.P. 2012. High river temperature reduces survival of sockeye salmon (*Oncorhynchus nerka*) approaching spawning grounds and exacerbates female mortality. Can. J. Fish. Aquat. Sci. 69: 330-342.	No relevant outcome
Matthews, I. 1999. Radio tagging adult Chinook salmon (*Oncorhynchus tshawytscha*) returing to the Whitehorse fishway -1998. Yukon Fish Game Assoc. 26 p.	No relevant outcome
Miller, K.M., Li, S., Kaukinen, K.H., Ginther, N., Hammill, E., Curtis, J.M.R., Patterson, D.A., Sierocinski, T., Donnison, L. Pavlidis, P., Hinch, S.G., Hruska, K.A., Cooke, S.J., English, K.K., and Farrell, A.P. 2011. Genomic signatures predict migration and spawning failure in wild Canadian salmon. Sci. 331: 214-217.	No relevant outcome
Morbey, Y.E., Anderson, D.M., and Henderson, B.A. 2008. Progress toward the rehabilitation of lae trout (*Salvelinus namaycush*) in South Bay, Lake Huron. J. Great Lakes Res. 34: 287-300.	No relevant outcome
Mowbray, F. and Locke, A. 1999. The effect of water temperature on angling catch of Atlantic salmon in the Upsalquitch River. DFO Can. Sci. Advis. Sec. Res. Doc. 99/056. 17 p. (Accessed January 13, 2017)	No relevant outcome
Newell, J.C., Fresh, K.L., and Quinn, T.P. 2007. Arrival patterns and movement of adult sockeye salmon in Lake Washington: implications for management of an urban fishery. N. Am. J. of Fish. Manage. 27: 908-917.	No relevant outcome
O'Farrell, M.R., and Satterthwaite, W.H. 2015. Inferred historical fishing mortality rates for an endangered population of chinook salmon (*Oncorhynchus tshawytscha*). NOAA Fish. Bull. 113: 341-351.	No relevant outcome
Okamoto, K.W., Whitlock, R., Magnan, P., and Dieckmann, U. 2009. Mitigating fisheries-induced evolution in lacustrine brook charr (*Salvelinus fontinalis*) in southern Quebec, Canada. Evol. Appl. 2: 415-437.	No relevant outcome
Orsi, J.A., Wertheimer, A.C., and Jaenicke, H.W. 1993. Influence of selected hook and lure types on catch, size, and mortality of commercially troll-caught chinook salmon. N. Am. J. Fish. Manage. 13: 709-722.	No relevant outcome
Pella, J., Rumbaugh, R., and Dahlberg, M. 1995. Incidental catches of salmonids in the 1991 North Pacific squid driftnet fisheries. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-AFSC-55: 33 p.	No relevant outcome

Full Reference	Reason
Pellett, K., Stiff, H.W., Damborg, J., and Hatt, K.D. 2010. A PIT-Tag based investigation into Somass River adult sockeye migration behaviour in response to environmental conditions, 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3116: vi + 173 p.	No relevant outcome
Pet, J.S., Machiels, M.A.M., and Van Densen, W.L.T. 1996. A size-structured simulation model for evaluating management strategies in gillnet fisheries exploiting spatially differentiated populations. Ecol. Modell. 88: 195-214.	No relevant outcome
Pitre, K.R. 1970. Summary of "shaker" investigations in the west coast of Vancouver Island troll fishery in 1968 and 1969. Depart. Fish. Forestry Pac. Region. Tech. Rep. 1970-1.	No relevant outcome
Policansky, D. 2008. Trends and development in catch and release. *In* Global challenges in recreational fisheries. Edited by A. Oystein. Wiley-Blackwell, Oxford. pp. 202-236.	No relevant outcome
Pon, L.B., Tovey, C.P., Bradford, M.J., MacLellan, S.G., and Hume, J.M.B. 2010. Depth and thermal histories of adult sockeye salmon (*Oncorhynchus nerka*) in Cultus Lake in 2006 and 2007. Can. Tech. Rep. Fish. Aquat. Sci. 2867: iii + 39 p.	No relevant outcome
Post, J.R., Mushens, C., Paul, A., and Sullivan, M. 2003. Assessment of alternative harvest regulations for sustaining recreational fisheries: model development and application to bull trout. N. Am. J. Fish. Manage. 23: 22-34.	No relevant outcome
Pritchard, A.L. 1947. Sockeye salmon migration in Babine River and Lake as indicated by tagging at Babine fence in 1947. Fish. Res. Board Can. Manuscr. Rep. Pacific Biological Station, Nanaimo, B.C. 536.	No relevant outcome
Quinn, T.P., Cooke, K.D., and Ellis, G. 1986. The response of adult sockeye salmon (*Oncorhynchus nerka*) to a commercial purse seine. Can. Tech. Rep. Fish. Aquat. Sci. 1511: 13 p	No relevant outcome
Quinn, W.S., Korver, R.M., Hicks, F.J., Monroe, B.P. and Hawkins, R.R. 1994. An empirical model of lentic brook trout. N. Am. J. Fish. Manage. 14: 692-709.	No relevant outcome
Risley, C.A.L., and Zydlewski, J. 2010. Assessing the effects of catch-and-release regulations on a brook trout population using an age-structured model. N. Am. J. Fish. Manage. 30: 1434-1444.	No relevant outcome
Ritter, J.A., Marshall, T.L., and Reddin, D.G. 1979. A review of non-catch fishing mortality as it related to Atlantic salmon (*Salmo salar* L.) fisheries. ICES C.M. 1979/M: 25.	No relevant outcome

Full Reference	Reason
Rosberg, G.E., and Greer, G.L. 1985. Migration rate and behaviour of adult sockeye and chum salmon through trained and untrained sections of the Lower Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1349: 25 p.	No relevant outcome
Rosseland, B.O., Lea, T.B., and Hansen, L.P. 1989. Physiological effects and survival of Carlin-tagged and descaled Atlantic salmon, *Salmo salar* L., in different water salinities. ICES C.M. 1982/M: 30.	No relevant intervention
Rowse, M.L. 1990. Chinook salmon and mortality associated with the 1988 Southeast Alaska purse seine fishery. Alaska Dep. Fish Game Tech. Fish. Rep. 90-03: ix + 43 p.	No relevant outcome
Sakuramoto, K., and Yamada, S. 1980. A study on the planting effect of salmon: a mathematical model for the derivation of their rate of return and its applications. Bull. Jpn. Soc. Sci. Fish. 46: 653-661.	No relevant outcome
Schubert, N.D. 1990. An assessment of five upper Fraser River chinook salmon sport fisheries, 1988. Can. Manuscr. Rep. Fish. Aquat. Sci. 2051: 58 p.	No relevant outcome
Schubert, N.D., and Scarborough, G.C. 1996. Radio telemetry observations of sockeye salmon (*Oncorhynchus nerka*) spawners in Chilko River and Chilko Lake: investigations of the role of stress in a mark-recapture study. Can. Tech. Rep. Fish. Aquat. Sci. 2131: 66 p.	No relevant outcome
Schubert, N.D., Whitehouse, T.R., and Cass, A.J. 1997. Design and evaluation of the 1995 Fraser River pink salmon (*Oncorhynchus gorbuscha*) escapement estimation study. Can. Tech. Rep. Fish. Aquat. Sci. 2178: 75 p.	No relevant outcome
Servizi, J.A., and Jensen, J.O.T. 1977. Resistance of adult sockeye salmon to acute thermal shock. Int. Pac. Salmon Fish. Comm. Prog. Rep. No. 34: 11 p.	No relevant intervention
Shetter, D.S., and Allison, L.N. 1955. Comparison of mortality between fly-hooked and work-hooked trout in Michigan streams. Michigan Dep. Conserv. Misc. Publ. No. 9: 44 p.	No relevant outcome
Shetter, D.S., and Hazzard, A.S. 1941. Results of plantings of marked trout of legal size in streams and lakes of Michigan. Trans. Am. Fish. Soc. 70: 446-468.	No relevant intervention
Sitar, S.P., Bence, J.R., Johnson, J.E., Ebener, M.P., and Taylor, W.W. 1999. Lake trout mortality and abundance in southern Lake Huron. N. Am. J. Fish. Manage. 19: 881-900.	No relevant outcome
Staley, M.J. 1990. Abundance, age, size, sex and coded wire tag recoveries for chinook salmon escapements of the Harrison River, 1984-1988. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2066: vii + 42 p.	No relevant outcome

Full Reference	Reason
Stapp, P., and Hayward, G.D. 2002. Estimates of predator consumption of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) in Yellowstone Lake. J. Freshw. Ecol. 17: 319-329.	No relevant outcome
Stohr, A.J.M., and Fraidenberg, M.E. 1986. A Delphi assessment of chinook and coho salmon hooking mortality. Washington Dep. Fish. Tech. Rep. 94.	No relevant outcome
Sullivan, C.L., Meyer, K.A., and Schill, D.J. 2013. Deep hooking and angling success when passively and actively fishing for stream-dwelling trout with baited J and circle hooks. N. Am. J. Fish. Manage. 33: 1-6.	No relevant outcome
Talbot, G.B. 1950. Biological study of the effectiveness of the Hell's gate fishways. Int. Pac. Sal. Fish. Comm. Bull. iii-1: 83 p.	No relevant outcome
Todd. I.S.P., and Larkin, P.A. 1971. Gillnet selectivity on sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) of the Skeena River system, British Columbia. J. Fish. Res. Board Can. 28: 821-842.	No relevant outcome
Underwood, T.J., Bromaghin, J.F., and Klosiewski, S.P. 2004. Evidence of handling mortality of adult chum salmon caused by fish wheel capture in the Yukon River, Alaska. North Am. J. Fish. Manage. 24: 237.243.	No relevant outcome
Vélez-Espino, L.A., McNicol, R.E., Brown, G., and Parken, C.K. 2010. Correction factors for numbers of released chinook salmon reported in commercial troll logbooks: expanding the applications of the observer program. Can. Manucr. Rep. Fish. Aquat. Sci. 2898: vii + 48 p.	No relevant outcome
Verhoeven, L.A., and Davidoff, E.B. Marine tagging of Frader River sockeye salmon. Int. Pac. Sal. Fish. Comm. Bull. XIII: 132 p.	No relevant outcome
Webb, J. 1992. The behaviour of adult salmon (*Salmo salar* L.) in the River Tay as determined by radio telemetry. Scottish Fish. Res. Rep. 52: 19p.	No relevant outcome
Westerberg, H., Lunneryd, S.G., Fjålling, A., and Wahlberg, M. 2006. Reconciling fisheries activities with the conservation of seals throughout the development of new fishing gear: a case study from the Baltic fishery-gray seal conflict. Am. Fish. Soc. Symp. 2006: 587-597.	No relevant intervention
Wilson, K.H., and Pearce, B.C. 1984. The relative selection of three mesh sizes of Fraser River sockeye gillnets for chinook salmon. Can. Tech. Rep. Fish. Aquat. Sci. No. 1250: ix + 71 p.	No relevant outcome
Wilson, K.H., and Andrew, J.H. 1987. Influence of gill net hang ratio on the catch of salmon in the Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1516: vii + 16 p.	No relevant outcome

Full Reference	Reason
Winship, A.J., O'Farrell, M.R., and Mohr, M.S. 2014. Fishery and hatchery effects on an endangered salmon population with low productivity. Trans. Am. Fish. Soc. 143: 957-971.	No relevant outcome
Witherell, D., Ackley, D., and Coon, C. 2002. An overview of salmon bycatch in Alaska groundfish fisheries. Alaska Fish. Res Bull. 9: 53-64.	No relevant intervention
Yale First Nation. 2001. Yale fishwheel and coho tagging program. DFO final report. HRSEP.	No relevant outcome
Zhou, S. 2002. Uncertainties in estimating fishing mortality in unmarked salmon in mark-selective fisheries using double-index-tagging methods. North Am. J. Fish. Manage. 22: 480-493.	No relevant outcome
Zhou, S. 2004. A pipeline model for estimating fishing mortality in salmon mark-selective fisheries. N. Am. J. Fish. Manage. 24: 979-989.	No relevant outcome
Zolotukhin, S., Makeev, S., and Semenchenko, A. 2013. Current status of the Sakhalin taimen, *Parahucho perryi* (Brevoort), on the mainland coast of the Sea of Japan and the Okhotsk Sea. Arch. Pol. Fish. 21: 205-210.	No relevant population

B.6 CODING SCHEME

Table B.6. Coding scheme used to systematically extract metadata information from the included articles to create a comprehensive map of evidence.

Category	Column name	Definition	Action
Bibliographic	ref.no	Unique reference ID	20XXXX
	authors	Authors	Last name, first initials., etc.
	title	Title	Free input
	pub.year	Year of publication	Date (yyyy)
	ref.type	Type of publication	Dropdown list
Study	primary.purpose.fishing	Is the objective of the study to evaluate fishing?	Yes/no
	other.purpose	Non-fishing objective of the study	Free input
	mark.recap	Study type - mark-recapture?	Yes/no
	telemetry	Study type - telemetry?	Yes/no
	holding	Study type - holding?	Yes/no
	transport.type	Means of study population relocation, where relevant	Free input
	study.location	Location of study	List large to small scale
	location.details	Water body location details	Free input
	study.year	Year of study	Date (yyyy)
	study.month	Month(s) of study	Date (mmm)
	study.realm	Realm of study	Marine/estuary/river/lake
	other	Other type of study	Free input
	notes	Notes on study	Free input
Population	sockeye	Species - sockeye?	Yes/no
	pink	Species - pink?	Yes/no
	chinook	Species - chinook?	Yes/no
	coho	Species - coho?	Yes/no
	steelhead	Species - steelhead?	Yes/no
	chum	Species - chum?	Yes/no
	other.oncorhynchus	Other species of study from genus *Oncorhynchus*	Free input
	salmo	Species of study from genus *Salmo*	Free input
	salvelinus	Species of study from genus *Salvelinus*	Free input
	pop.agg	Population aggregate of study	Free input
	life.stage	Life stage of study	Free input - e.g. adult, subadult
	other	Other population of study	Free input
	notes	Notes on population	Free input- e.g. hatchery, wild

Category	Column name	Definition	Action
Intervention	angling	Intervention - angling?	Yes/no
	purse.seine	Intervention - purse seine?	Yes/no
	beach.seine	Intervention - beach seine?	Yes/no
	gill.net	Intervention - gill net?	Yes/no
	tangle.net	Intervention - tangle net?	Yes/no
	dip.net	Intervention - dip net?	Yes/no
	troll	Intervention - troll?	Yes/no
	simulation	Intervention - simulated?	Yes/no
	other	Other intervention of study	Free input
	notes	Notes on intervention	Free input
Biology	species	Level of information on species presented?	Comment/report/sign. or non-sign.
	sex	Level of information on sex presented?	Comment/report/sign. or non-sign.
	age	Level of information on age presented?	Comment/report/sign. or non-sign.
	size	Level of information on size presented?	Comment/report/sign. or non-sign.
	maturity	Level of information on maturity presented?	Comment/report/sign. or non-sign.
	disease	Level of information on disease presented?	Comment/report/sign. or non-sign.
	metab.status	Level of information on metabolic status presented?	Comment/report/sign. or non-sign.
	osmoreg.status	Level of information on osmoregulatory status presented?	Comment/report/sign. or non-sign.
	capt.behav	Level of information on capture behaviour presented?	Comment/report/sign. or non-sign.
	release.behav	Level of information on release behaviour presented?	Comment/report/sign. or non-sign.
	pre.capt.injury	Level of information on pre-capture injury presented?	Comment/report/sign. or non-sign.
	capt.injury	Level of information on capture injury presented?	Comment/report/sign. or non-sign.
	other	Other biological information presented	Free input
	notes	Notes on biological information presented	Free input
Environment	water.temp	Level of information on water temperature presented?	Comment/report/sign. or non-sign.
	water.current	Level of information on water current presented?	Comment/report/sign. or non-sign.
	salinity	Level of information on salinity presented?	Comment/report/sign. or non-sign.
	diss.oxygen	Level of information on dissolved oxygen presented?	Comment/report/sign. or non-sign.
	other	Other environmental information presented	Free input - e.g. water hardness
	notes	Notes on environmental information presented	Free input
Fishing	capt.type	Level of information on capture type presented?	Comment/report/sign. or non-sign.
	gear.variation	Level of information on fishing gear variation presented?	Comment/report/sign. or non-sign.
	method.variant	Level of information on fishing method variation presented?	Comment/report/sign. or non-sign.
	depth	Level of information on fishing depth presented?	Comment/report/sign. or non-sign.
	capt.time	Level of information on fishing capture duration presented?	Comment/report/sign. or non-sign.
	handl.time	Level of information on handling duration presented?	Comment/report/sign. or non-sign.
	handl.tech	Level of information on handling technique presented?	Comment/report/sign. or non-sign.

Category	Column name	Definition	Action
	handle.exp	Level of information on handler experience presented?	Comment/report/sign. or non-sign.
	air.time	Level of information on air exposure duration presented?	Comment/report/sign. or non-sign.
	fish.density	Level of information on density of catch presented?	Comment/report/sign. or non-sign.
	species.comp	Level of information on composition of catch presented?	Comment/report/sign. or non-sign.
	recover.type	Level of information on recovery gear type presented?	Comment/report/sign. or non-sign.
	recover.time	Level of information on recovery duration presented?	Comment/report/sign. or non-sign.
	other	Other fishing-related information presented	Free input
	notes	Notes on fishing information presented	Free input
Outcome	depredation	Mortality - depredation?	Yes/no
	drop.off	Mortality - drop off?	Yes/no
	imm.mort	Mortality - immediate mortality?	Yes/no
	0-24h	Mortality - 0 to 24 hr post-release?	Yes/no
	0-48h	Mortality - 0 to 48 hr post-release?	Yes/no
	0-72h	Mortality - 0 to 72 hr post-release?	Yes/no
	0-96h	Mortality - 0 to 96 hr post-release?	Yes/no
	0->96h	Mortality - 0 to greater than 96 hr post-release?	Yes/no
	terminal	Mortality - spatial endpoint?	Yes/no
	main.outcome	Main mortality results	Free input
	notes	Notes on mortality outcomes	Free input
	sublethal.behav	Behavioural outcomes presented	Free input - e.g. migration rate
	sublethal.physio	Physiological outcomes presented	Free input - e.g. plasma stress indices
	other	Other outcomes presented	Free input - e.g. growth rate
	notes	Notes on non-mortality outcomes	Free input
Quality	study.realism	Relevance - realism of intervention	Real/manipulated/simulated
	samp.size	Reliability - sample size?	Yes/no
	ref.fish	Reliability - reference fish?	Yes/no
	replication	Reliability - replication?	Yes/no
	stat.analysis	Reliability - statistical analyses	Free input
	other	Other quality assessment measures	Free input
	notes	Notes on quality	Free input
	our.comments	Overall quality comments	Free input